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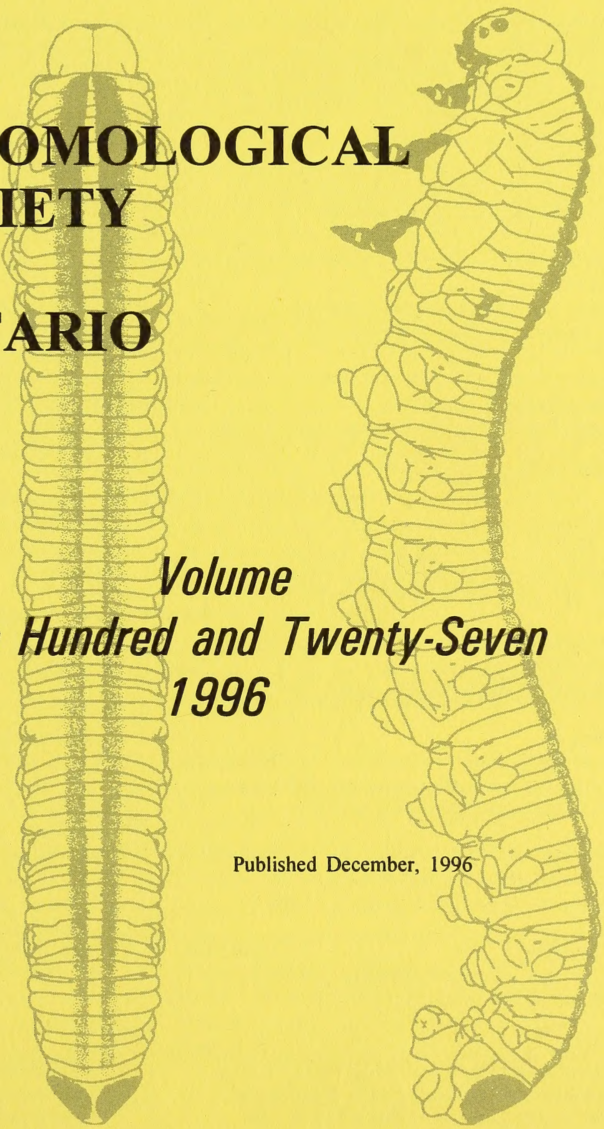

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Cover illustration: Dorsal and lateral view of larva of Swaine jack pine sawfly (*Neodiprion swainei*) Middleton drawn by Don Wallace.

PROCEEDINGS

of the

ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume 127 ***1996***

From the Editor,

Now that volume 127 is out of my hands and in yours, it is time that we, the membership of the Society, do some hard thinking about the future of our Proceedings. There is no immediate reason to doubt the continued health of this publication; what is at stake, though, is its future format. Scientific journals printed with black ink on white paper have been the mainstay of communication in most scientific disciplines for the past couple of centuries. However, just as clay tablets, papyrus scrolls and parchment have become obsolete media for mankind's information transfer, bound bundles of paper are about to as well. My guess is that before the first decade of the 21st Century is out, most journals as we know them will have ceased to exist. What will have taken their place, or into what form they will have metamorphosed, and by what means, is a hot issue of current debate.

Electronic transfer of information is already a sizeable component of the total. Many of us no longer do our literature searches flipping through reference books in the library, but facing our PC in our own office. Informal sharing of information via e-mail provides us with closer and better informed contact with colleagues all over the world. Some journals, somewhat hesitantly, have started to publish electronically. What should be our policy? Joining a revolution is a difficult course of action; spearheading one is fraught with pitfalls, but also has the sweet taste of adventure. What strategy should we, the ESO, adopt for the future format of our journal?

I want to propose a future course of action. I hope that some of you, both the membership and non-member readers, will respond with constructive criticism. Whatever we do, we will penetrate into *terra incognita* which is risky, but doing nothing could well be the most likely strategy to fail. So, please send me comments (preferably by e-mail).

Our prime objectives should be: 1) to reach as large an audience as the publication deserves, 2) to decrease the time between research and publication, 3) to use modern technology so as to increase the usefulness of the publication for readers and researchers, especially our membership, and 4) to do the above at reasonable cost.

The proposed strategy is as follows. First, we place all titles, abstracts and author's addresses on the ESO web site (this information is also available on Biological Abstracts and some other reference works). The next move (I would like to start this for the 1997 volume) is to encourage some authors to submit their work for partial electronic publication. I recognize that some papers are of the kind that we like to read in full; for instance, the paper by Virginia Walker and co-workers in last year's issue. Other papers we read only if they are in our own area of endeavour. The most extreme form of the latter type is the voluminous annotated checklist, or revision of some genus or subfamily. It is this kind of paper that would benefit most from electronic publication. It would be cheaper, would reach a wider audience, and above all would allow for feedback and updating. Such papers will appear in the Proceedings as an abstract, an introduction, an extended 1-2 page summary, and instructions for how to access the entire text, maps, tables and line drawings on our website, as well as instructions for contacting the author for feedback. Such papers would be subjected to the full review process, and listed as published in the Proceedings. For instance, had we followed the proposed method, the paper by Bob Skidmore which we published in Vol. 126 would be referenced as:

Skidmore, R.E. 1995. Checklist of Collembola (Insecta: Apterygota) of Canada and Alaska. Proc. ent. Soc. Ont. 126: 45-46 (plus 31 pp on http://www.utoronto.ca/forest/eso/eso.htm).

Any revision which includes the description of new species would have to include the species description in the printed text due to international regulations, but the greater part of such publications also could be on our web site. Similarly, until computer technology improves, scanning EM photographs will be printed in the journal.

Authors of such papers would probably not order any reprints, reducing somewhat the income we normally receive from the sale of reprints, but both the author through much reduced page charge costs, and the Society, through reduced printing costs would on balance save. The Proceedings would be thinner, but the membership would, as readers, have access to as much or more information and, as authors, have greater access to an international readership. I invite your comments, and hope that we can come to an agreement on a policy which will get us a major step closer to the 21st Century; a century in which the Proceedings will continue to play a significant role as a vehicle for the dissemination of entomological information.

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FROM SAWFLIES TO SOLENOIDS: A TRIBUTE TO DONALD RAYMOND WALLACE

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In a review of forest entomology in Canada [34], Don Wallace stated "… as a nation in which the forest environment looms so large, we should capitalize on these assets and build upon the foundation that Canadian entomologists have established". Don's own career in forest entomology both contributed to and built upon that foundation. Following his graduation from Bishop's

University in 1951 with a Bachelor of Science degree in Biology and Chemistry, Don was hired by the Forest Biology Division, Canada Department of Agriculture, and attached to the Forest Insect and Disease Survey Unit in Sault Ste. Marie. Here, he took an active part in regional operations specifically related to ecological investigations of forest insects in Ontario. Some of his earliest research revealed what was to become a career-long interest in the effects of weather on insects [1]. He served in the Survey Unit until 1959.

During the same period, Don was introduced to another career-long passion; sawflies. With the strong recommendation of M.L. Prebble, Chief of the Forest Biology Division, and B.M. McGugan, Co-ordinator of the Forest Insect and Disease Survey, and with the support of R.M. Belyea, Officer-in-Charge of the Forest Insect Laboratory, Sault Ste. Marie, Wallace agreed in 1954 to take on *Neodiprion* larval studies on behalf of the Division, part of which would lead to his Master's Degree. The project was a co-operative study with R. Lambert of the Systematic Entomology Unit who was doing complementary studies of *Neodiprion* adults. At the time, Wallace was already undertaking postgraduate training at MacDonald College of McGill University under the supervision of E.M. DuPorte. One can only speculate that perhaps Don's decision to take on this work may have coloured his opinion of Prebble when he revealed Prebble's covert nickname in an otherwise glowing tribute [35]. During these early years, Wallace made an extensive collection of sawflies from Ontario and throughout North America and, as a result, established a network of collaborators that represented a who's who of forest entomology. In a 1955 letter to Belyea, he proposed the investigations of *Neodiprion swainei* that would lead to his M.Sc. dissertation [4]. During the next couple of years, Don divided his time between his *Neodiprion* research and his duties with the Survey Unit. He worked diligently to delineate the distribution of *N. swainei* and its jack pine host [2]. He was convinced that investigations of the ecology and physiology of insect species were needed to support a morphological approach to taxonomy. This is evident in the paper, co-authored with A.W. Ghent, in which behavioural observations of oviposition were discussed in an evolutionary context [3].

In 1959, Wallace discovered that oocyte colour and the corresponding biochemical differences among eggs were useful taxonomic characteristics in the diprionid sawflies. This discovery formed the basis of his Ph.D. thesis [8] and subsequent publications [9, 10]. He had, by this time, begun work with I.M. Campbell on the genetic variation in *N. swainei*. Thus, the main thrust of his research from 1959 until 1969 continued to be the taxonomy and biology of the immature stages of pine sawflies in the subfamily Diprioninae of the Diprionidae. The oft stated purpose of the research was to provide a sound systematic revision of the diprionine sawflies and to provide a rapid means for their identification by non-specialists. A recent review of diprionid sawflies by Wallace demonstrated the depth and breadth of his knowledge [41].

Early in the 1960's, Don's interest in the ecology and evolution of sawflies led him to recognize that "the phenomenon of diapause plays an important part in determining the seasonal history of pine sawflies and in doing so may be a critical factor in speciation". His interest in diapause closely paralleled that of C.R. Sullivan. Thus, they formed a collaboration in which they investigated the environmental factors regulating seasonal history of *N. sertifer*. The fruits of this collaboration were bountiful. Early research looked at the effects of temperature on development [7], effect of photoperiod and temperature on diapause [11, 12, 13, 15], and the occurrence of inclusion bodies in sawflies and their effects on fecundity [16, 17].

Don's congenial nature and insights continually opened up new collaborations. The continuing quest for the elusive tool to help differentiate the taxa of *Neodiprion* led Wallace, in collaboration with C.H. Schaefer of the U.S. Forest Service, to examine the amino acid composition of the hemolymph of nine species of the genus [14]. They found that there was as much variation within species as there was between species in their amino acid constituents. Much, however, was learned about the biochemistry of the genus. A rather significant milestone in Wallace's career was the discovery, with S.G. Smith, of sex alleles in *N. nigroscutum*, the first to be found in the lower Hymenoptera [18].

In 1965-1966, Don took a sabbatical leave and served as Visiting Professor in the Department of Entomology at the University of Wisconsin. Here, he assumed responsibility for teaching undergraduate courses in forest entomology and served as mentor to postgraduate students within the discipline. As well, he had the opportunity to associate and become friends with D.M. Benjamin, H.C. Coppel and others.

By the late 1960's, support for basic and fundamental entomological research within the Canadian Forestry Service was beginning to decline in favour of more emphasis on problem-oriented research with immediate application to pest management problems of the times. As a result of this change in research policy, emphasis in Wallace's research shifted. Although his project on *Neodiprion* biology and taxonomy would be continued on a maintenance basis, he was asked by G.W. Green, Entomology Section Head at the time, to join a research group using *Neodiprion sertifer* as a model for the development of alternatives to insecticides in insect pest management systems. This brought Don in close formal working contact not only with C.R. Sullivan with whom he had collaborated extensively in the past but also with L.A. Lyons and K.J. Griffiths, all of whom had extensive knowledge of sawfly biology. Out of this restructuring emerged several new studies, one of which was entitled "Behavioural and developmental characteristics of forest insects that are relevant to the elucidation and testing of control principles" to be conducted by Wallace and Sullivan. This reorganization formalized what had already become a long-lasting collaboration and friendship between these two entomologists that would continue to result in significant contributions to forest entomology. In this period they developed a technique for the continuous rearing of eggs of *N. sertifer* [22], extended their knowledge of diapause in *N. sertifer* [24, 25], explored the photoperiodic response of other *Neodiprion* species [21, 23] and reviewed the biology of the white pine weevil [33]. Some of the knowledge accrued by Wallace and his colleagues about the biology of *N. sertifer* was summarized in a review article that emphasized its biological control [26]. With typical foresight, Don realized that the enormous amount of ecological data that had been accumulated about *N. sertifer* could be used to develop a simulation model of the sawfly's life history system. The modeling was contracted to C.S. Holling of the Institute of Animal Resource Ecology at the University of British Columbia but the biological input was supplied by Don and his colleagues. Don served as the Scientific Authority for the contract.

Several factors combined by 1973 to again shift the focus of Wallace's research. The economic importance of conifer sawflies was on wane; the gypsy moth, *Lymantria dispar*, was emerging as a potentially serious threat to the forests of Ontario; and greater emphasis was being placed on the search for alternatives to chemical insecticides for control of damage caused by spruce budworm, *Choristoneura fumiferana*. Sullivan and Wallace by this time had correctly predicted that temperature would not be a key factor limiting the northern distribution of gypsy moth in Ontario [20]. Although eggs of gypsy moth only had a mean supercooling point of about −30°C, they concluded that eggs deposited beneath an insulating cover of snow could survive much lower air temperatures. In the next three years, research on *N. sertifer* was completed and new investigations into the biology of the gypsy moth were initiated. At this time Sullivan had moved to a research management position and in 1976 a new project had emerged entitled "Insect Control Research with Special Reference to the Gypsy Moth" with Wallace as the Project Leader.

One of Don's many talents was his understanding, appreciation and innovative use of technology. Engineers, technicians, graduate students and colleagues sought and willingly received his advice on scientific equipment ranging from thermostats to data loggers. His comprehension of spectrophotometry stood him in good stead in his work on sawfly taxonomy [9, 10]. This work proved to be a first in the application of spectrophotometric analysis of egg pigmentation to insect taxonomic problems. It provided a new and innovative approach to unraveling the hopelessly confused problem associated with the taxonomy of *Neodiprion* sawflies. In the early days, when environmental equipment was required, Wallace, Sullivan and Green constructed it [11]. The same was true for experimental work on the effects of photoperiodism on spore germination in *Entomophthora canadensis* [27]. It is not difficult to surmise what Wallace's contribution was to the study of the effect of temperature on spruce budworm flight [29]. Don's penchant for tools was not just for sophisticated technology. He was equally ingenious at adapting simple devices to solve novel problems, such as his use of a modified leafblower for field release of the egg parasitoid, *Trichogramma minutum* [37]. During renovation to the laboratory in Sault Ste. Marie, he was responsible for acquiring state-of-the-art environmental chambers and rearing facilities. He took it upon himself to make sure that the equipment was perfectly calibrated and operating within acceptable parameters. He also recognized the importance of having a quarantine rearing facility in the Sault Ste. Marie laboratory to be used for the importation and study of exotic insects for biological control. Once again he worked closely with engineers in its design in order to bring the facility up to his high standards. He was also instrumental in selecting and obtaining a scanning-electron microscope for the Sault Ste. Marie laboratory.

A recurring theme in Don's research career was the role of biological control in the mitigation of forest insect populations. In an early review of diprionid sawflies attacking pines [5], Don recognized the value of virus applications and parasitoids in their control. Some of the biological control projects in which he has participated have included acquisition, evaluation, classical introduction and assessment of parasitoids of gypsy moth [28]; larch sawfly, *Pristophora erichsonii*; European pine sawfly, *N. sertifer*; and Swaine jack pine sawfly, *N. swainei*, as well as inundative releases of *T. minutum* (see below).

Fungal pathogens are promising biological control agents of forest insect pests, but their potential can only be realized if they can be successfully propagated. Wallace and Sullivan were approached by D.M. McLeod concerning a problem in the germination of resting spores of the entomopathogen, *E. aphidis (=canadensis)*. Using knowledge and experience gained in studying diapause and dormancy in insects, significant strides were made in understanding the germination physiology of these organisms. Using techniques suggested by Wallace, it was shown that good germination of resting spores requires a 14 h daylength [27, 30], occurs at an optimum temperature [31], and can be empirically modeled [32].

In the spring of 1981, a study entitled "Mass Release of Parasitoids" was initialized by Wallace and Griffiths which focused on the behaviour of *T. minutum* as a suitable parasite for possible release against spruce budworm. One year later an aerial release trial was carried out in Ontario. The project caught the interest of government, industry and universities, and led to Wallace representing the Canadian Forest Service's interests on the *Trichogramma* Advisory Committee for this interagency project. Sandy M. Smith coordinated the project in subsequent years as part of her Ph.D. research at the University of Toronto. Don's contributions to the project are outlined in a series of articles authored or co-authored by him [36, 37, 38, 39]. Following completion of her Ph.D., S.M. Smith was hired on a Visiting Fellowship (1985-1987) with the Canadian Forest Service under Wallace's supervision. During this same period, he also served on the graduate/examination committee for the Ph.D. research by Y.H. Prevost on "The relationship between the development of cones of black spruce *Picea mariana* (Mill.) B.S.P. and their insect fauna" at the University of Guelph. Don was appointed as an Associated Member of the Faculty of Graduate Studies and administered the project which was conducted from the laboratory in Sault Ste. Marie. Coincidentally, both Y.H. Prevost (1995) and S.M. Smith (1996) have gone on to serve terms as Presidents of the Entomological Society of Ontario.

After a sojourn to China in 1986 to attend the 2nd International Symposium on *Trichogramma* and Other Egg Parasites, Wallace saw the progress the Chinese had made and became fascinated with the concept of the development of an artificial egg. He also realized the potential of China as a source of classical biological control agents for Canada. Unfortunately, declining health prevented him from returning to China, but he was able to pursue biocontrol interactions with the Chinese and host visiting scientists. Mr. Zhang Jianguo worked for one year in Canada under Wallace's tutelage.

Don's knowledge of, and dedication to, biological control are evident in several reviews he published on the subject [40, 42, 43]. He formulated, and chaired until his retirement, the Biological Control Working Group of the Canadian Forest Service which developed policy and guided national and international programmes. As well, he served as a member of the Canadian Forum for Biological Control, Northeastern Working Group on Biological Control and the International Organization for Biological Control.

Wallace was a member of the Entomological Society of Ontario, Entomological Society of Canada, Entomological Society of America, Canadian Society of Zoologists, American Association for the Advancement of Science, International Society of Hymenopterists, Forest Protection Subcommittee of the Ontario Forestry Research Committee and the Planning Group for Research Priorities Relating to the Impact of Climate Change on the Forests of Canada. In 1993, he was elected President of the Entomological Society of Ontario.

As a project leader, Wallace developed a multidisciplinary research team to understand the population dynamics of forest insects in Ontario. As a Senior Scientist, he contributed to the development of other research programs at Ontario Region and elsewhere in the Canadian Forest Service. In 1993, he retired from the Canadian Forestry Service and in June 1994 was awarded Scientist Emeritus status.

Don was a consummate and highly principled scientist, a gentleman and a very broadly knowledgeable guy. He was always ready to share his knowledge and capabilities with others with his continuing wit and cheery smile, whatever the odds.

Acknowledgements

I would like to thank Don's friends and colleagues, G.W. Green, G.T. Harvey, V.G. Nealis and C.R. Sullivan, who contributed to this tribute.

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CANADIAN FIELD RELEASES AND OVERWINTER SURVIVAL OF *CERANTHIA SAMARENSIS* (VILLENEUVE) (DIPTERA:TACHINIDAE) FOR BIOLOGICAL CONTROL OF THE GYPSY MOTH, *LYMANTRIA DISPAR* (L.) (LEPIDOPTERA: LYMANTRIIDAE)

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Abstract

Proc. ent. Soc. Ont. 127: 11-20

Successful Canadian field releases of the European tachinid fly, *Ceranthia samarensis* (Vill.), an endoparasitoid of the gypsy moth, *Lymantria dispar* (L.), are reported. With the exception of 1993, at least 200, and as many as 600, gravid female adult flies have been released each year between 1991 and 1996 in southeastern Ontario. Releases of parasitized host larvae and puparia of *C. samarensis* were also made. In 1992 and 1994, releases of gravid adult flies were made into large cages enclosing entire oak trees onto which young gypsy moth larvae had been released. In 1991, 1995 and 1996, free releases of adult parasitoids were made, although trees in the immediate vicinity of the release were seeded with susceptible age-classes of gypsy moth larvae. Each year of assessment, evidence of successful parasitism by field-released females was observed. Retrieved progeny of released flies were all in diapause. Experimental exposures of diapausing, pharate adult *C. samarensis* to overwintering conditions in the release sites showed that overwinter survival of the parasitoid can be expected to be quite high in Ontario. Most observed mortality was the result of local predators, parasitoids, and disease organisms. A monitoring programme to confirm successful establishment of the biological control agent is now recommended.

Introduction

Classical biological control programs introducing exotic parasitoids of the gypsy moth, *Lymantria dispar* (L.), into North America have been carried out for nearly 100 years. Over that period, more than 60 species of natural enemies have been introduced, mostly into the northeastern states of the United States, and approximately one-quarter of these species are confirmed as established (Reardon 1981; Coulson *et al.* 1986). Several of these established species of natural enemies have dispersed widely from the areas of original introduction and can be found attacking gypsy moth in a large portion of its present range in North America. Surveys in southern Ontario and Québec between 1977 and 1980 indicated that eleven species of parasitoids introduced to the

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United States were active in gypsy moth populations in Canada (Griffiths and Quednau 1984).

Most introduced parasitoid species attacking gypsy moth in North America are associated with outbreak populations of the host. This is not surprising considering that much of the effort has been directed to discovering and collecting parasitoids from outbreak populations of the gypsy moth in its native, Eurasian range and the intensive monitoring of outbreak populations in the North American range of the gypsy moth. Thus, although the classical approach may have successfully established species that mitigate outbreaks of the gypsy moth by suppressing high-density populations of the pest, these natural enemies appear to have done little in preventing the increase and spread of populations of the gypsy moth in North America.

In 1980, the Canadian Forest Service and CAB International Institute of Biological Control initiated a novel approach to biological control of the gypsy moth. This new approach was based on the premise that different phases in the population cycle of an eruptive forest defoliator such as gypsy moth are characterized by distinctive guilds of natural enemies (Pschorn-Walcher 1977; Mills 1990). The introduction of parasitoids associated with low-density populations of the gypsy moth would complement the natural enemy fauna of outbreak populations and, ideally, lead to more stable dynamics of the pest by retarding and perhaps even preventing the rapid build-up of gypsy moth populations in susceptible habitats. Field work in Europe focussed on discovery of parasitoids associated with persistently low densities of the gypsy moth. Sentinel host larvae were employed in this phase of the project as this had proven to be a useful method in the highly successful biological control of the mountain-ash sawfly in North America (Quednau 1990). This collection technique led to the discovery of the siphonine tachinid, *Ceranthia samarensis* (Villeneuve), apparently common in low density populations of the gypsy moth in west-central Europe. Small releases of *C. samarensis* collected in Europe were made in Canada in the late 1980s (Mills and Nealis 1992).

Ceranthia samarensis is associated with low-density populations of the gypsy moth. It is therefore difficult to secure sufficient material for releases from field collections alone. In 1989, experimental work leading to the establishment of a laboratory colony was undertaken at the Laurentian Forestry Centre in Québec. Since little was known of the biology of *C. samarensis* at the time, detailed knowledge of the parasitoid's reproductive biology had to be ascertained (Quednau 1993). Once the biological requisites of the species had been identified, sufficient material could be produced for field releases and experimental work to further examine the biological feasibility of introducing this parasitoid into North America. This paper reports on field releases of *C. samarensis* made in Ontario since 1991, and on the results of field experiments to examine overwinter survival of the parasitoid. The results enhance our expectations of successful establishment of *C. samarensis* as a biological control agent against the gypsy moth in North America.

Methods

Releases. Releases of *C. samarensis* were carried out between 1991 and 1996 at two locations in southeastern Ontario: Olden Township (76°51′W; 44°40′N) and Marmora Township (77°35′W; 44°30′N). Refer to Table I for details of the releases. No rigorous estimates of gypsy moth density were made in the release sites during this period, although regular observations of gypsy moth under burlap bands on trees were made throughout the study. Both sites had been severely defoliated in 1986 and 1987 and populations had generally declined since that time. Noticeable defoliation persisted in Olden Township through to 1991 and there was little difficulty in collecting

TABLE I. Details of dates, locations, release rates, methods, and assessments for biological control program using *Ceranthia samarensis* in Ontario. See text for exact locations and description of results.

Date		Location	Released	Method	Assessment
1991:	29 May	Olden Twp.	142 gravid females	open release	50 gypsy moth larvae collected and reared, no evidence of *C. samarensis*
	5 June		110 gravid females		
1992:	21 May	Olden Twp.	220 gravid females	cage release	puparia recovered in drop cones
	27 May		160 gravid females		
	6 July	Marmora Twp.	1000 parasitized hosts	placed on foliage	puparia recovered from soil
	6 July		175 puparia	exposed in soil-filled fox	successful emergence of overwintered adults in following spring
1994:	1 June	Olden Twp.	200 gravid females	cage release	puparia recovered in drop cones
	3 June		200 gravid females		
	7 June		150 gravid females		
1995:	26 May	Olden Twp.	400 gravid females	open release	puparia recovered in drop cones
	31 May		200 gravid females		
1996:	27 May	Olden Twp.	200 gravid females	open release	no assessment

several hundred larvae under burlap traps on trees up to 1996. Populations of gypsy moth in Marmora Township were consistently lower than in Olden and releases of *C. samarensis* were suspended after 1992 in that site.

All *C. samarensis* used in the releases were obtained from a stock colony maintained by F.W. Quednau in Québec. The general procedure used for rearing the insect is given by Quednau (1993). Most releases involved gravid adult female parasitoids (Table I). In these cases, the insects were mated and allowed to ovilarviposit in the laboratory before being taken to the field so that all released individuals were known to be fecund and conditioned to the host. They were transported to the field in dark coolers to reduce activity, and released in late afternoon. Releases of adults in 1992 and 1994 were made into large cages (4 m x 4 m x 6 m) constructed of metal scaffolding and covered in white, synthetic screening (Fig. 1). These cages enclosed whole oak trees to which several thousand early-instar gypsy moth had been added two days previous to releases. In 1991, 1995, and 1996 open releases of gravid females were made. Trees in the vicinity of the releases in those years were also seeded with several thousand early-instar gypsy moth just prior to the release.

In 1992 two alternative release methods were used: 1) gypsy moth larvae previously exposed to *C. samarensis* in the laboratory were released onto small (< 5 m) oak trees and, 2) puparia with pharate adult *C. samarensis* in diapause were placed in the field in a soil-filled wooden box and left to overwinter and emerge the following spring.

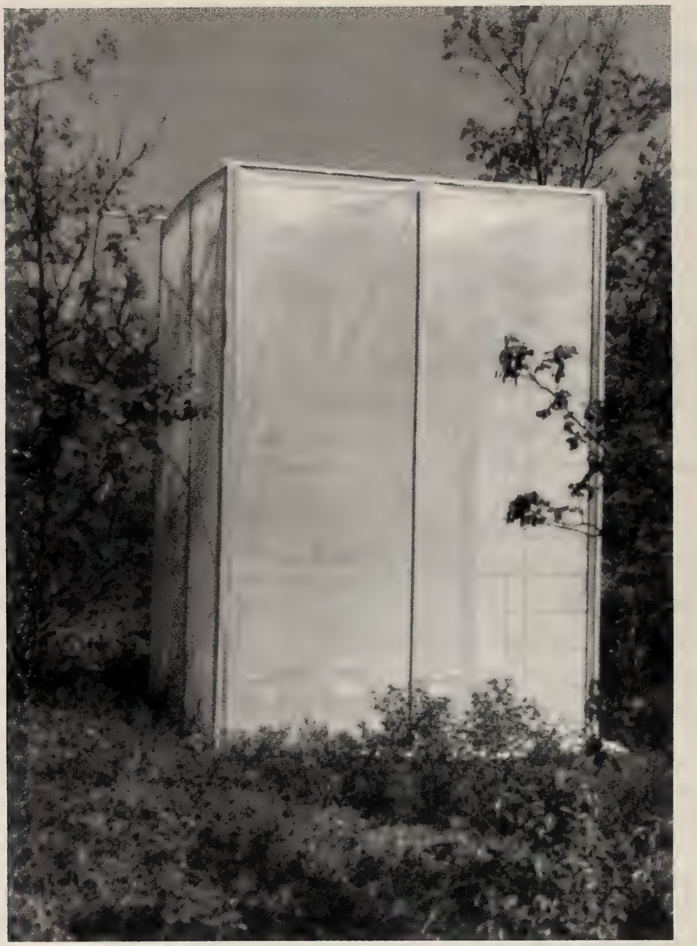

FIGURE 1. Cage enclosing whole oak trees used for releases of *Ceranthia samarensis* in 1992 and 1994.

To retrieve emerging progeny of released adult *C. samarensis*, 30 sheet-metal drop cones, each with a mouth of 1 m^2, were grouped beneath trees that had been seeded with gypsy moth larvae (Fig. 2). These cones emptied into 0.5 litre plastic bottles to which sawdust was added. *Ceranthia* larvae falling into these receptacles were able to form normal puparia. Puparia were all collected at the end of the season and held at room temperature to determine viability.

Overwinter survival. A preliminary investigation of overwinter survival of *C. samarensis* was made in 1992-1993 at the Marmora Township site. One hundred seventy-five puparia containing pharate adult *C. samarensis* in diapause were placed in a soil-filled wooden box and placed in the field on 6 July 1992. Survival was assessed the following June (1993) by retrieving the box and

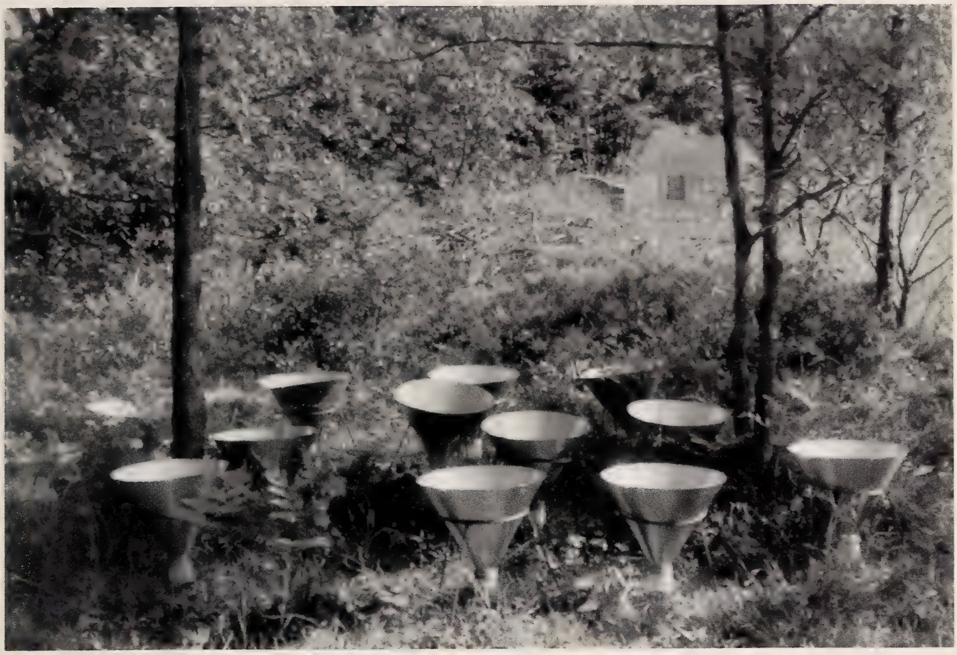

FIGURE 2. Drop cones used for collecting emerging puparia of *Ceranthia samarensis.*

contents and examining the recovered puparia.

A more critical examination of overwinter survival was made in 1995-1996. In this experiment, puparia with pharate adult *C. samarensis* in diapause were placed at the two release sites on 18 July 1995. These were retrieved the following spring (1996) and survival assessed. Insects used in the experiment were from laboratory stock and so there was no possibility of hyperparasitism before exposure to field conditions. Diapause in *C. samarensis* had been induced by rearing parasitized gypsy moth larvae at 20°C during the day and 15°C during the night. Once the parasitoid larva had emerged from the host and formed a puparium, it was stored at constant 15°C. Photoperiod was always L:D 12:12. Puparia were placed on a bed of local soil in 7 cm diameter clay flower pots and then covered in moist peat to a depth of approximately 2 cm. The pot was covered with stainless steel mesh (2 mm) held in place with a hose clamp to exclude large predators. Pots, containing approximately 20 puparia each, were placed in holes in the ground at the release sites. Grass and light debris were brushed over the top of the pots. Controls consisted of retaining a random subsample of the puparia in pots and holding these at controlled temperatures in the laboratory. These control pots with puparia were placed in a larger container filled completely with wet peat. Water was added to the peat periodically to moderate changes in humidity in the artificial environment. These puparia were held at 15°C, L:D 16:8 for three months and then placed at 5°C, L:D 12:12 for the remaining six months.

Half of the field-exposed puparia were retrieved on 23 April 1996 before natural emergence of either gypsy moth or parasitoids. The protective screen covers were removed from the remaining half to permit emerging adult *Ceranthia* to escape. The retrieved puparia were returned to the laboratory, removed from the peat and placed on moist filter paper in a Petri dish. This dish was placed in larger, plastic emergence chamber that maintained near-saturated humidity. The emergence chambers were placed at 22°C, L:D 16:8 and the number of successfully emerging flies was counted. After three weeks, all remaining puparia were examined to determine their fates. Puparia that had been held under controlled conditions were incubated in the same manner at the same time. The rest of the *C. samarensis* puparia overwintered in the field were collected 28 May 1996. These were returned to the laboratory and held for 5 days at 22°C. All puparia were then examined. Examination of the puparia from all treatments permitted their assignment to one of several fates. Successfully emerged *C. samarensis* left a characteristic opening at the anterior end of the puparium. Parasitoids attacking *C. samarensis* in the field also left characteristic emergence holes in the middle of the puparium. A round exit hole indicated parasitism by a chalcidoid and an oblong hole indicated parasitism by an ichneumonoid. Predators left more irregular, yet distinctive, holes in the puparia. Undisturbed, intact puparia were classified as either viable when they contained a pharate adult *C. samarensis*, or dead as a result of unknown causes when, as was often the case, the contents of the puparium were desiccated or mouldy.

Percentage survival was calculated in two ways. Overall rate of survival was simply the total number of emerged and viable adult *C. samarensis* divided by the total number of puparia retrieved. This rate is the expected survival of the introduced insect under natural conditions. The rate of survival in the laboratory controls, of course, included no losses resulting from predation or parasitism of puparia. A second rate of survival, therefore, was calculated for the field data excluding observed mortality resulting from the action of natural enemies. This rate of survival is the appropriate one to compare with the control to ascertain losses in the field resulting from physical and physiological factors associated with overwintering.

Results and Discussion

Releases. Gravid, female *C. samarensis* proved to be fairly robust during ovilarviposition and during transportation to the field. The greatest attrition was during the gestation period in the laboratory (Quednau 1993). Released adults flew readily and were soon observed sitting on foliage. No actual attacks on gypsy moth were observed in the field, but successful parasitism was confirmed in 1992, 1994, and 1995 by finding fully-formed puparia in the drop cones. No assessment was carried out in 1996. Over the three years of assessment, a total of 19 puparia were recovered from drop cones, and all *C. samarensis* recovered were in diapause. Similarly, release of gypsy moth larvae parasitized by *C. samarensis* in 1992 resulted in puparia of the parasitoid formed in the soil at the release site although no detailed search was made to estimate numbers for fear of disturbing the site. Details of the assessments of all releases are given in Table I.

Overwinter survival. Eighty-five of the 175 puparia exposed to winter conditions in 1992-1993 were assessed. A total of 34 (40%) of the puparia examined indicated successful survival and emergence of adult *C. samarensis*. The remainder were damaged by predators or were mouldy.

The results of the 1995-1996 study of overwinter survival can be given in more detail. Overall rate of survival of insects retrieved from the field sites is shown by the cross-hatched bars in Fig. 3. These estimates of survival include losses resulting from predation and parasitism of puparia in the field. Rates of predation and parasitism on puparia are presented separately in Table II. In Olden Twp., total losses to predators and parasitoids were not greatly different between the April and May collection dates (26% and 18%, respectively) whereas at the Marmora Twp. site, there

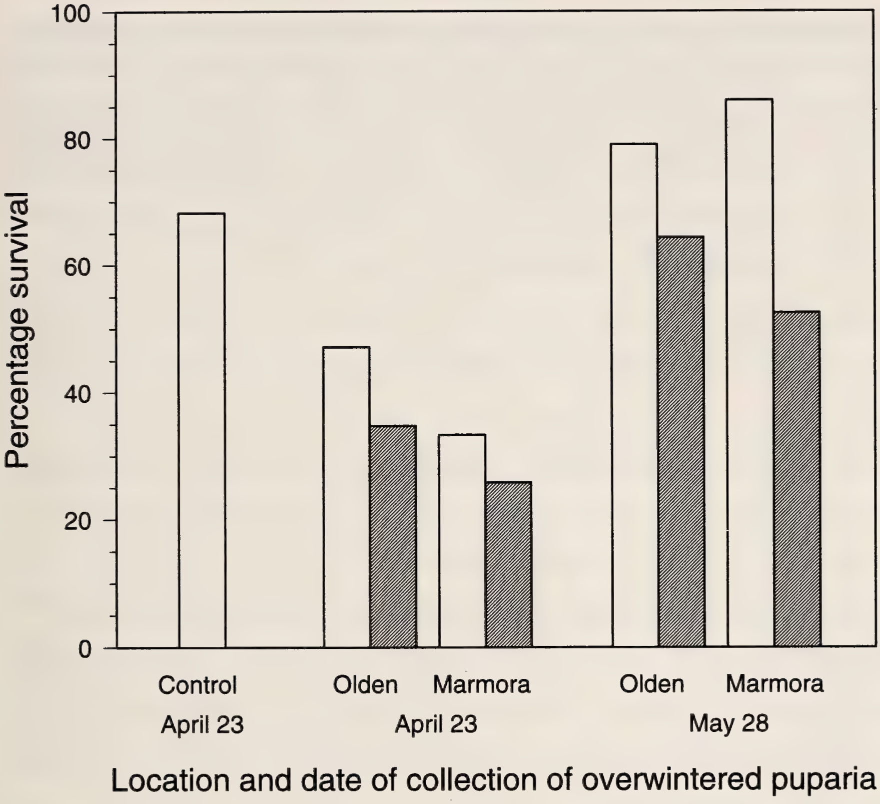

FIGURE 3. Percentage survival of puparia of *Ceranthia samarensis* exposed to natural conditions in two locations in southern Ontario and under controlled conditions in the laboratory between 12 July 1995 and 23 April 1996 and 28 May 1996. Cross-hatched bars represent overall survival in the field and include losses due to predation and parasitism. Open bars represent overwinter survival excluding losses from natural enemies.

was an increase in the overall losses resulting from natural enemies between April and May (22% and 39%, respectively). In both sites, the apparent increases in predation in the May collection was associated with decreases in parasitism suggesting that whatever spring predation did occur, it may have been selective on parasitized puparia of *C. samarensis*. The rate of survival from winter conditions alone was best estimated by first excluding these losses due to natural enemies. This rate of overwinter survival is given by the open bars in Fig. 3. These estimates of overwinter survival excluding mortality from natural enemies are the most appropriate estimates to compare to the laboratory control where parasitism and predation were excluded experimentally.

Overwinter survival of puparia held under controlled conditions was 68% (58 of 85 insects) (Fig. 3). This compares closely to earlier laboratory estimates of post-storage rates of emergence for *C. samarensis* (Quednau 1993). Overwinter survival of *C. samarensis* in the field excluding

TABLE II. Puparia of *Ceranthia samarensis* attacked by invertebrate predators and parasitoids in experimental exposures 12 July 1995 to 23 April 1996 and 28 May 1996 at two locations in Ontario.

Location	Date of Collection	Number of Puparia Recovered	Number of Puparia Parasitized	Number of Puparia Predated	Total Losses (percentage)
Olden Twp.	23 April 1996	118	21	10	31 (26)
	28 May 1996	115	5	16	21 (18)
Marmora Twp.	23 April 1996	124	11	17	28 (22)
	28 May 1996	80	3	28	31 (29)

mortality due to natural enemies was 47% (41 of 87) and 79% (74 of 94) in Olden Twp. for puparia retrieved on 23 April and 28 May, respectively, and 33% (32 of 96) and 86% (42 of 49) in Marmora Twp. for those same collection dates, respectively. The consistently lower estimate for the earlier collection date at both sites is an artifact of measurement. As described in the methods section, none of the puparia retrieved on the earlier date (23 April) had emerged at the time of collection and were held under warm conditions for several days after emergence in the laboratory was completed. Unemerged, dissected puparia after this lengthy incubation period were all desiccated and gave little hint as to their condition at the time of collection. The puparia collected on the later date (28 May), however, were actually emerging during the week of the collection and additional emergence was observed within a few days of returning these insects to the laboratory. Unemerged puparia were dissected a few days following the last observed emergence. Surprisingly, there were several puparia (56) from both sites that still contained fully viable, pharate adult *C. samarensis*. These individuals had survived the winter in the field but apparently had not completed diapause development. Presumably, many of the insects scored as not surviving in the earlier field collection were also pharate adults that had survived the winter but did not emerge. In our opinion, it was the long exposure to warm laboratory conditions, not natural winter conditions, that killed them. Consequently the estimate of overwinter survival based on observations of the April collections underestimates actual survival. The May collections are the most accurate indicators of the overwintering success of *C. samarensis* in the release locations.

Conclusions

The results described here provide empirical evidence that the biological requisites for successfully introducing *C. samarensis* into Ontario can be met, and establishment of this biological control agent of the gypsy moth may be already occurring. Either gravid adults or immature stages (larvae in hosts or free-living pharate adults in puparia) can be easily transported to the field where they survive well and carry out normal biological functions. Progeny produced from released adults entered diapause, suggesting that *C. samarensis* will be largely univoltine in Ontario; a desirable characteristic for biological control of the gypsy moth (Mills and Nealis 1992). Diapause stages survived both the summer and winter very well. Predation and parasitism on soil-dwelling puparia was substantial (25% overall) but much less than has been estimated for other introduced parasitoids of the gypsy moth (Bourchier and Nealis 1992). Survival of the introduced parasitoids overwinter seems exceptionally good; the main physiological source of mortality appeared to be failure to terminate diapause and this may have been an artifact of rearing conditions. Another possible explanation is that some individual *C. samarensis* have an extended diapause. Further investigations into both diapause induction and diapause termination in *C. samarensis* are clearly needed. Those insects that did emerge eclosed in late May at about the same time that very young gypsy moth larvae were present on the trees. Thus the phenology of these artificially implanted parasitoids seems to be appropriate for local conditions.

Given the relatively small number of insects introduced and the relatively low fecundity of *C. samarensis* (Quednau 1993), we expect that establishment of the parasitoid in Ontario may be difficult to confirm for several more years. *C. samarensis* is, after all, a parasitoid associated with low-density population levels of its host, so high local densities of the parasitoid are not expected (Mills 1990). Nonetheless, this parasitoid was first collected by exploiting its tendency to aggregate on artificial infestations of gypsy moth larvae on a few trees within an area of very low density of the gypsy moth. If *C. samarensis* has indeed become established in Ontario, a monitoring programme using sentinel hosts such as were used in the original collections in Europe may be an effective way to gain proof of success sooner than would otherwise be possible.

Acknowledgments

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AERIAL SPRAY TRIALS WITH NUCLEAR POLYHEDROSIS VIRUS AND *BACILLUS THURINGIENSIS* ON GYPSY MOTH (LEPIDOPTERA: LYMANTRIIDAE) IN 1994
I. IMPACT IN THE YEAR OF APPLICATION

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Abstract

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Aerial spray trials were conducted with Disparvirus (nuclear polyhedrosis virus) and Foray 48B (*Bacillus thuringiensis* subsp. *kurstaki*) in Pinery Provincial Park near Grand Bend, Ontario to control gypsy moth, *Lymantria dispar* (L.). Test plots, with predominantly black oak trees, were 10 ha in area. Larvae were in their first instar when spraying commenced on 27 May 1994 and were at the peak of the second instar when Foray 48B was applied on 9 June. Oak leaves were about 22% expanded at the start of the operation and 50% expanded when it finished. The virus was formulated in Novo Nordisk Carrier 244; dosage was a double application of 5×10^{11} polyhedral inclusion bodies (PIB)/ha (total 10^{12} PIB/ha) with applications 6 days apart. Two volumes were tested, 5.0 L/ha and 2.5 L/ha. The Foray was applied as a single application of 50 billion international units (BIU) in 4.0 L/ha. Each treatment was replicated on 5 plots.

A detailed assessment involved pupal counts under burlap traps, defoliation estimates, microscopic diagnosis of levels of nuclear polyhedrosis virus infection pre-spray, and pre- and post-spray egg-mass counts. Pupal counts and defoliation in treated plots were significantly lower ($p<0.05$) than those in untreated check plots. Egg-mass counts were adjusted to reflect overwintering mortality; post-spray egg-mass counts in all treated plots were below a threshold level of 1,250/ha (above which retreatment may be required) and only 1 of 5 check plots was below this figure. Population reductions due to treatment were calculated using a modified Abbott's formula and average egg-mass reductions were 76% for the Disparvirus treatment at 5.0 L/ha, 80% for Disparvirus at 2.5 L/ha and 96% for the Foray 48B treatment.

Introduction

Since the early part of this century, occasional collections of gypsy moth, *Lymantria dispar* (L), have been made in eastern Canada in areas adjacent to infested American locations (Nealis and Erb 1993). In 1969, first defoliation was noted in southeastern Ontario and in 1982 an aerial spray trial was undertaken using nuclear polyhedrosis virus (NPV), *Bacillus thuringiensis* subsp. *kurstaki* (*B.t.k.*) and Sevin® (Meating *et al.* 1983). An intensive programme was launched in 1988 to develop an NPV product called Disparvirus in Canada. A registration for this product was submitted in 1990 and is currently under review. Aerial spray trials were conducted each year from 1988 until 1994 and over 1,300 ha were treated with NPV (Cunningham *et al.* 1991; Cunningham *et al.* 1993; Cunningham *et al.* 1997).

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In the USA, NPV, originally called wilt disease, was recognized as a potential control agent for gypsy moth and field trials were conducted in 1913 (Glaser and Chapman 1913). In 1963, a ground spray trial was conducted by USDA Forest Service staff (Rollinson *et al.* 1965) followed by a series of aerial spray trials (Yendol *et al.* 1977; Wollam *et al.* 1978; Lewis *et al.* 1979). Toxicological and environmental impact studies were also conducted and a registration petition presented to the Environmental Protection Agency for a product called Gypchek® that received approval in 1978. An appropriate tank mix for this NPV has always presented problems although satisfactory results have been obtained with mixtures of molasses, lignosulphonates as ultraviolet (UV) protectants and appropriate stickers (Podgwaite 1985; Reardon *et al.* 1994). The USDA Forest Service, in collaboration with Novo Nordisk Bioindustrials, Inc., developed a carrier for Gypchek. This material, called Carrier 244, was made available for field testing in Canada in 1994.

The Pinery Provincial Park was heavily defoliated by gypsy moth in 1993 and was considered an ideal area for field trials in 1994. Populations of gypsy moth were generally low throughout the Province of Ontario at this time. Besides Disparvirus, a *B.t.k.* product, Foray 48B (Novo Nordisk Bioindustrials, Inc.), was included in the trials as a comparative positive control to the Disparvirus treatments.

Materials and Methods

Plots

Plots were located in Pinery Provincial Park, near Grand Bend, Ontario. The Pinery Provincial Park has a total area of about 2,400 ha. Plots treated with Disparvirus were 210 x 480 m, giving an area of 10 ha. A block, 5 km x 210 m, with an area of 105 ha along the park boundary was treated with Foray 48B (*B.t.k.*) and within this strip five 10 ha plots were measured out. There was a buffer zone of at least 200 m between all plots (Fig. 1). All plots contained more than 90% oak; mainly black oak, *Quercus velutina* Lam., is found in this area, although white oak, *Q. alba* L., is also present, as well as hybrids. A description of the 20 plots is given in Table I, with the number of stems per ha, diameter at breast height (DBH), and pre-spray gypsy moth egg-mass (E.M.) density.

Treatments

Two NPV treatments were replicated on five 10 ha plots and a further five 10 ha plots were monitored as untreated check plots. The Foray 48B treatment was applied on a 105 ha block in which five 10 ha plots were selected and used in the experiment. Treatments are listed in Table II. The virus applications used 90% Carrier 244 (Novo Nordisk Bioindustrials, Inc.) with the technical virus powder suspended in 10% water and added to the carrier. The first virus treatment was a double application, 6 days apart, of 5×10^{11} polyhedral inclusion bodies (PIB)/ha (total 10^{12} PIB/ha) in an emitted volume of 5.0 L/ha. The second virus treatment was the same as the first, but the emitted volume was 2.5 L/ha. The *B.t.k.* treatment used Foray 48B with a single application

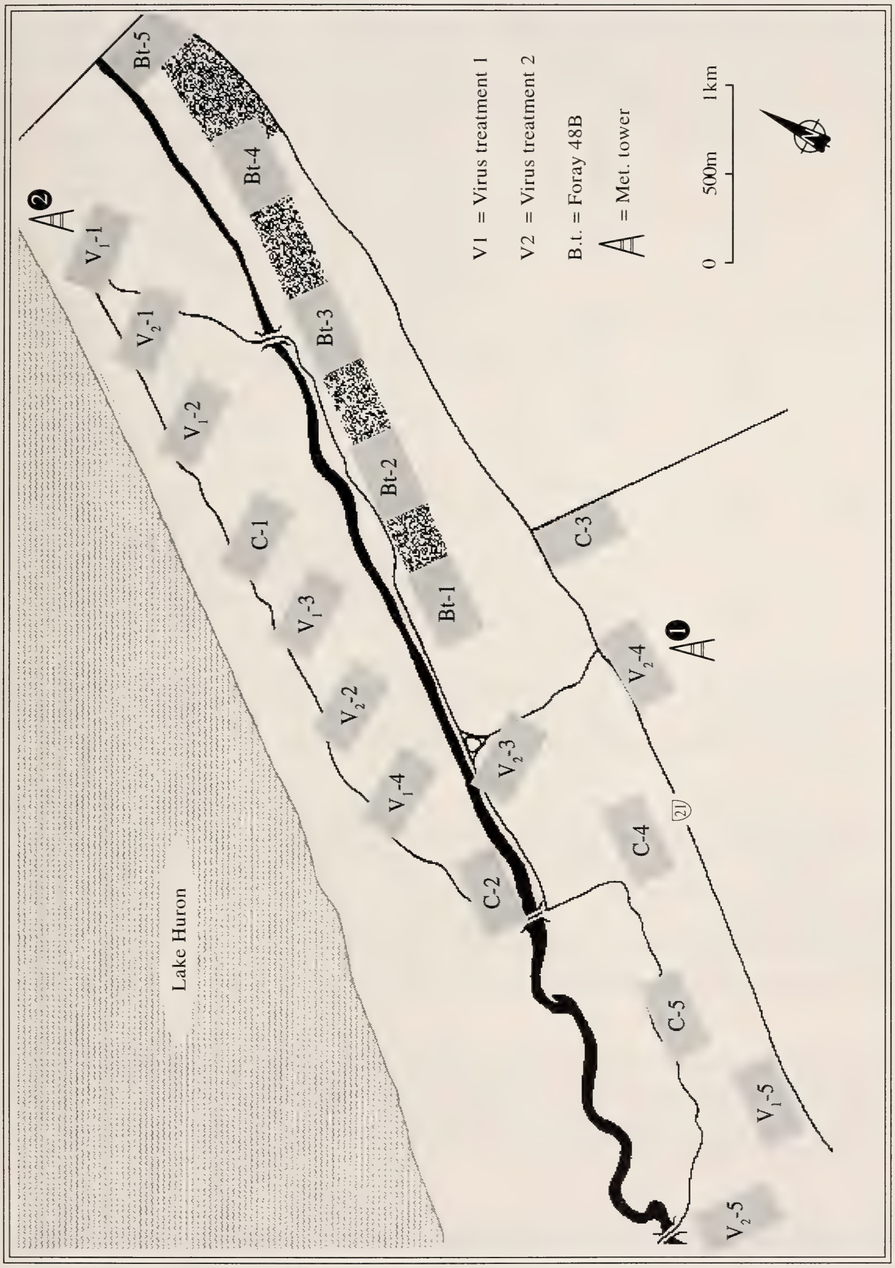

FIGURE 1. Location of plots treated with Disparvirus and Foray 48B in Pinery Provincial Park, 1994.

TABLE I. Description of plots used for 1994 field trials in Pinery Provincial Park.

Treatment	Plot	No. of stems/ha	DBH[a] (cm) of sample	Average no. of pre-spray E.M.[b]/ha (± SE)[c]
Virus 1	1	580	30.2 ± 1.8	24,510 ± 3,286
	2	385	34.1 ± 1.5	14,715 ± 6,903
	3	495	28.5 ± 1.2	21,120 ± 4,306
	4	555	29.4 ± 1.8	31,590 ± 2,873
	5	405	31.9 ± 2.3	19,325 ± 2,578
Virus 2	1	460	29.1 ± 1.4	15,890 ± 2,867
	2	435	28.1 ± 1.2	3,560 ± 691
	3	535	30.6 ± 1.5	15,650 ± 1,690
	4	490	34.9 ± 1.8	11,637 ± 2,701
	5	520	29.9 ± 1.6	11,175 ± 1,521
B.t.k.[d]	1	555	23.4 ± 1.2	1,440 ± 204
	2	500	30.3 ± 1.4	1,925 ± 342
	3	550	24.0 ± 1.1	8,330 ± 1,171
	4	475	26.3 ± 1.4	25,490 ± 2,111
	5	505	20.8 ± 2.6	12,135 ± 1,051
Check	1	505	30.4 ± 1.2	3,460 ± 682
	2	435	27.3 ± 1.3	8,980 ± 1,320
	3	445	22.2 ± 1.1	7,130 ± 758
	4	445	30.5 ± 1.4	5,630 ± 771
	5	406	29.7 ± 2.3	18,165 ± 1,930

[a] DBH = diameter at breast height.
[b] E.M. = egg-masses
[c] SE = standard error
[d] *Bacillus thuringiensis* subsp. *kurstaki*

of 50 billion international units (BIU) in 4.0 L/ha. Erio acid red at 0.2% was added to all tank mixes to allow deposit quantification. To identify the plots from the air, the centre lines were marked using white, helium-filled balloons. Seven swaths, 30 m wide, were used to treat each plot and the 105 ha block sprayed with *B.t.k.*

Aerial spray applications

A Cessna 188 Agtruck fitted with 4 Micronair® AU4000 atomizers using a 55° blade angle and rotating between 5,600 and 6,200 rpm was used for the NPV applications and rotation speed was 5,400 to 6,200 rpm for the *B.t.k.* application. Designated swath width was 30 m, flying speed 176 km/h and height above the canopy was 10 to 15 m. The NPV treatments were between 27 May and 3 June. The first application of virus treatment 1 was between 08:15 and 09:40 on 27

TABLE II. Aerial spray treatments on gypsy moth larvae each replicated on 5 plots in Pinery Provincial Park, 1994.

Treatment	Material applied	Dosage PIB[a] or BIU[b]/ha	Number of applications	Days apart	Application rate (L/ha)
Virus 1	Disparvirus in Novo Carrier 244	5 x 10^{11} PIB/ha	2	6	5.0
Virus 2	Disparvirus in Novo Carrier 244	5 x 10^{11} PIB/ha	2	6	2.5
B.t.k.[c]	Foray 48B	50 BIU/ha	1	-	4.0
Untreated check	None	-	-	-	

[a] PIB = polyhedral inclusion bodies
[b] BIU = billion international units
[c] *Bacillus thuringiensis* subsp. *kurstaki*

May and the second application on 2 June between 20:45 and 21:25. The first application of virus treatment 2 was between 07:00 and 08:00 on 28 May and the second application on 3 June between 06:10 and 07:05. The *B.t.k.* application was on 9 June between 06:25 and 06:55.

Meteorological measurements

Two 12 m towers were erected with the first in virus plot V_2-4 and the second in virus plot V_1-1 (Fig. 1). Tower 1 was about 2.5 km from the shoreline of Lake Huron and tower 2 about 0.5 km. Temperatures were measured at 2.4 m and 10.7 m, relative humidity at 7.6 m and wind speed and direction at 12.0 m. Instruments were sampled at 1 sec intervals and 5 min averages were logged using a CR10 data logger (Campbell Scientific Instruments). A summary of the meteorological conditions during spray applications is given in Table III.

Host and insect pest development

Insect development. Insect development was determined by examining 100 larvae collected on the morning of the spray application. On 27 and 28 May, all larvae were in their first instar. On 2 June, 70% were first instar and 30% second instar and on 3 June, 70% were first, 28% second and 2% third instar. On 9 June, at the time of the *B.t.k.* application, 40% were first instar, 48% second instar and 12% third instar.

Host tree phenology. At each plot, 20 leaves on black oak trees were measured at 2 to 3 days prior to the first two spray applications and on the last three spray days. The same leaves were measured again when fully expanded. Leaves were 17% expanded on 24 May, 22% on 25 May, 41% on 2 June, and 50% on 3 June and 9 June. Pre-spray defoliation was limited to shot-holes in the foliage and was <5%.

TABLE III. Meteorological conditions during spray applications in Pinery Provincial Park, 1994.

Date (Time)	Tower 1 (inland)			Tower 2 (near Lake Huron)			Stability
	Air temp °C	% RH[a]	Wind speed km/h	Air temp °C	% RH[a]	Wind speed km/h	
May 27 (08:15-09:40)	5-7	93-62	0.4-3.6	6-7	82-73	1.9-5.2	Stable-neutral
28 (07:00-08:00)	8-9	73-60	0.4-1.4	8-10	68-56	1.5-3.4	Stable
June 02 (20:45-21:25)	11	66-70	2.3-1.3	11	70	5.5-2.3	Stable-neutral
03 (06:10-07:05)	3-4	98	0.0	3-4	96	0.3-1.4	Stable
09 (06:25-06:55)	3	97	0.0	3-4	95	0.4-1.5	Stable

[a] RH = relative humidity

Deposit sampling and assessment

Spray deposits on oak leaves and artificial foliage at two heights in the forest canopy were sampled as well as on Kromekote® cards and stainless steel plates on the ground. Samples were taken at four sites in each of the virus-treated plots (20 sites per virus application) and at 20 sites in four of the plots treated with *B.t.k.* At each sampling site, a halyard was placed in a deciduous tree and used to mount natural and artificial foliage samplers at heights of 7-9 m and 10-12 m, corresponding to mid- and upper-crown levels. Artificial foliage comprised Kromekote cards and polyethylene leaves with silhouette areas of 43 cm^2 per leaf suspended on fine wire supports and oriented close to horizontal. Oak branch tips, 10 to 15 cm in length, were mounted at the same heights. At each sampling site a 10 cm x 10 cm Kromekote card and two 20 cm x 20 cm stainless steel plates were placed on the ground.

Spray droplet densities (stains/cm^2) on oak foliage were measured within 48 h of sample collection by examining upper and lower surfaces of the leaves under UV light, with 5 to 10 leaves assessed from each sample; five 1 cm^2 areas were scanned on both the upper and lower surfaces; stain diameters were not measured, due to uneven spreading. Stain densities were recorded on "Kromekote artificial foliage" and on cards placed on the ground, and stains were sized and corrected for spread factor. Spray deposits on polyethylene artificial leaves and stainless steel ground plates were quantified by fluorometry and compared to samples of the tank mixes to determine the amount of tank mix deposited.

Egg-mass counts

Twenty 0.01 ha (10 m x 10 m) sub-plots containing at least three oak trees were established in each treated and untreated check plot. All new egg-masses (laid the previous year and identified by colour and, where possible, texture) on the tree trunks and branches were counted and egg-masses from ten 1 m^2 areas on the ground were also counted. Binoculars were used to count egg-masses higher in the trees. The number of egg-masses on the ground was multiplied by 10 and added to the numbers counted above ground. This figure, in turn, was multiplied by 100 to convert it to number of egg-masses per hectare. There was considerable overwintering mortality of egg-masses in Pinery Provincial Park in the winter of 1993/94. A survey was conducted to determine the percentage of egg-masses that had not hatched below the snow line at 60 cm and above the snow line between 60 cm and 1.8 m with 10 egg-masses collected above and below the snow line in each plot and placed individually in plastic petri dishes. Pre-spray egg-mass counts were adjusted for overwinter mortality in subsequent calculations to determine the effectiveness of the applications. Pre-spray egg-mass counts were made in April and May and post-spray counts in late October when ground vegetation had lost its leaves.

Incidence of virus infection

Fifty larvae were collected before the spray applications between 24 May and 6 June from all the treated and check plots (total 1,000 larvae) to determine the incidence of naturally occurring NPV. These larvae were smeared on microscope slides for microscopic diagnosis. Insect tissue smears were fixed in absolute alcohol for 1 min and thoroughly rinsed with tap water. Slides were then placed in Naphthalene Black 12B (1.5% w/v) at 40°-45°C for 10 min, rinsed in tap water for 1 min and air dried. They were examined at X 1,000 under bright field for PIBs that stain blue. Smears containing PIBs were scored as positive.

Pupae in burlap traps

Strips of burlap 45 cm wide were folded double, making the trap 22.5 cm wide, and nailed loosely at 1.5 m to the trunks of three oak trees in each of the 20 egg-mass survey sub-plots in all the treated plots and the untreated check plots. When pupation reached 90%, insects were counted with pre-pupae and healthy larvae scored as pupae. The circumference of each tree was measured at 1.5 m and the count per burlap trap converted to number of pupae per linear metre of burlap.

Defoliation estimates

Five 45 cm oak branch tips were collected at mid-crown using pole pruners from each of the 20 egg-mass survey sites in each plot. All the leaves on the tips were examined. Totally consumed leaves, recognized by the remaining petioles, were scored as 100% defoliated. Intact leaves were removed and scored as 0% defoliated. Partially eaten leaves were removed individually and the amount of foliage eaten was estimated. An overall defoliation figure for each branch tip was then calculated. It takes 10 to 15 min to estimate defoliation on each branch tip and is used as a training procedure. Once familiar with different levels of defoliation, three observers made a visual assessment of each branch and reached a consensus. The mean for each sub-plot was calculated followed by the overall figure for the 100 branch samples from each treated plot and each check plot.

Statistical analysis

The Mann-Whitney (Wilcoxon) rank-sum test was used to compare two independent samples

(Conover 1980) while the Kruskal-Wallis (1952) one-way analysis of variance was applied to the problem of comparing more than two independent samples. The BMDP statistical software programme 3S (nonparametric statistics) was used to perform the tests. In the statistical analysis of the egg-mass count data, spring and fall egg-mass counts on individual 0.01 ha sub-plots were paired and this figure was used to calculate the population change. To compute population reduction attributed to treatments, a modified Abbott's formula (Abbott 1925) was used.

Results

Spray deposits

A summary of measured spray droplet densities from the virus and *B.t.k.* treatments is presented in Table IV. Data from sampling sites with no observable spray deposit were excluded from the analysis. These were observed on the upwind side of virus-treated plots and the proportion of sites at which no deposits were observed was 10, 13 and 6% for natural foliage, artificial foliage and ground cards, respectively. Moderately good deposits were obtained in the virus sprays with average spray drop densities /cm^2 ranging between 0.9 and 2.0, and 0.8 and 3.0 on the top leaf surfaces at upper- and mid-crown levels, respectively. Artificial foliage showed somewhat higher deposits, ranging from 5 to 8 and 5 to 7 on the upper surfaces at upper- and mid-crown levels, respectively. The closer proximity and sheltering of the natural leaves and their variable orientation probably accounted for the difference observed between natural and artificial leaves. Average deposit densities on ground cards were similar to those on artificial foliage and ranged from 4 to 8 drops. Canopy penetration was good as indicated by similar deposit levels at the two canopy levels and on the ground. Deposits were predominantly on the upper surfaces. Spray droplet densities obtained in the 5.0 and 2.5 L/ha applications were generally similar. Spray drop sizes are given in Table V. The average volume median diameter (VMD) and number median diameter (NMD) on artificial foliage was 167 μm and 66 μm and was similar to values of 181 μm and 88 μm from cards placed on the ground. The volume of spray deposited averaged 20% at mid-crown on artificial foliage and 18% on plates on the ground (Table V).

Spray droplet densities from the *B.t.k.* application were variable and 25% of sites were found to have no observable deposit on the natural foliage, artificial foliage or ground cards. Spray deposits were much higher in plots 1 and 2 (*B.t.k.*A) than in plots 3 and 5 (*B.t.k.*B) and they were analyzed separately (Table IV). In plots 1 and 2, average number of drops was very high on the upper surfaces of real and artificial foliage at upper- and mid-crown levels with 30 and 31/cm^2 and 17 and 16/cm^2, respectively, with 12/cm^2 on ground cards. Densities were considerably lower on the undersides of leaves. Spray droplet densities in plots 3 and 5 were similar to those recorded from the virus applications with 3 and 4 drops/cm^2 at upper- and mid-crown on real foliage, 4 and 5 on artificial foliage, and 6 on ground cards. Spray droplet sizes were 99 and 55 μm for the VMD and NMD on artificial foliage and 146 and 72 μm on ground samplers (Table V).

Incidence of virus infection

A total of 1,000 larvae, collected prior to the spray applications, was microscopically diagnosed for virus infection. Plots ranged from 0 to 10% of larvae infected with an average level of 3.9% NPV infection (Table VI).

Pupal counts

The numbers of pupae per linear metre of burlap are given in Table VI. The mean number

TABLE IV. Spray droplet densities (average ± SD[a]) on oak leaves, artificial foliage and ground cards in Pinery Provincial Park, 1994.

Treatment (application)		Oak leaves		Artificial foliage		Ground cards
		Upper[b]	Mid[b]	Upper	Mid	
Virus 1 (1)	T[c]	2 ± 5	3 ± 5	7 ± 8	6 ± 4	6 ± 4
	B	1 ± 3	1 ± 3	0.2 ± 1	0.04 ± 0.2	
Virus 1 (2)	T	1 ± 2	0.8 ± 2	6 ± 5	5 ± 6	4 ± 2
	B	0.2 ± 0.7	0.3 ± 1	0.06 ± 0.2	0.08 ± 0.3	
Virus 2 (1)	T	0.9 ± 2	0.8 ± 2	5 ± 4	5 ± 4	5 ± 3
	B	0.2 ± 0.5	0.4 ± 0.9	0.04 ± 0.3	0.04 ± 0.3	
Virus 2 (2)	T	1 ± 2	1 ± 2	8 ± 6	7 ± 6	8 ± 5
	B	0.2 ± 0.5	0.1 ± 1	0.06 ± 0.3	0.01 ± 0.1	
B.t.k.[d] A[e]	T	31 ± 16	30 ± 20	17 ± 13	16 ± 13	12 ± 5
	B	2 ± 7	3 ± 9	0 ± 0	0 ± 0	
B.t.k.[d] B[e]	T	3 ± 3	4 ± 3	4 ± 3	5 ± 4	6 ± 4
	B	0.3 ± 1	1 ± 2	0 ± 0	0 ± 0	

[a] SD = standard deviation

[b] Canopy level

[c] T and B denote data from the top and bottom of foliar surfaces

[d] *Bacillus thuringiensis* subsp. *kurstaki*

[e] A and B denote data from *B.t.k.* plots 1 and 2 and plots 3 and 5, respectively

of pupae/m was similar in the three treatments, 5.9, 6.4 and 4.6 for the two virus treatments and the *B.t.k.* treatment, respectively, and significantly different ($p<0.05$; Mann-Whitney rank-sum test) from the untreated check plots at 43.0.

Defoliation estimates

Defoliation estimates are shown in Table VI. Defoliation was light in all the treated plots with averages of 18.6% and 19.0% in the two virus treatments and 25.2% in the *B.t.k.* treatment. The range was considerable in the check plots, from 22.0 to 73.7% with a mean of 47.1% which was significantly greater ($p<0.05$; Mann-Whitney rank-sum test) than the treatments.

Egg-mass counts

Pre-spray egg-mass counts from the 15 treated and 5 untreated check plots are given in Table I and the counts corrected for overwintering mortality are given in Table VI. The uncorrected

TABLE V. Deposited spray drop sizes and percent deposited on artificial foliage and ground samplers in Pinery Provincial Park, 1994.

Treatment (application)		Artificial foliage (mid-crown)			Ground samplers		
		VMD (µm)	NMD (µm)	% Volume deposited	VMD (µm)	NMD (µm)	% Volume deposited
Virus 1 (5.0 L/ha)	(1)	196	72	18 ± 14	200	76	10 ± 8
	(2)	171	49	8 ± 6	153	59	8 ± 4
Virus 2 (2.5 L/ha)	(1)	194	75	28 ± 48	227	128	20 ± 12
	(2)	106	66	24 ± 28	142	88	32 ± 36
B.t.k.[a] (4.0 L/ha) (average A & B)		99	55	-[b]	146	72	-[b]

[a] *Bacillus thuringiensis* subsp. *kurstaki*

[b] data not available

counts ranged from 1,440 to 31,590/ha and the adjusted counts from 1,224 to 13,728/ha. There was no difference in overwintering mortality from the two levels sampled. Post-spray egg-mass counts were made in late October (Table VI). There were significant reductions between pre-spray counts and post-spray counts in all three treatments compared to the untreated check plots ($p<0.05$; Mann-Whitney rank-sum test). The mean post-spray egg-mass counts ranged from 105 to 970/ha in the two virus treatments with a mean of 447 for the 5.0 L/ha treatment and a mean of 375 for the 2.5 L/ha treatment compared with a mean of 81 in the *B.t.k.* treatment. The mean of the untreated check plots was 1,598 egg-masses/ha.

There was a major population crash in check plot 5 which had the highest pre-spray egg-mass count; this plot was considered atypical and was not used in calculations of population reductions due to treatment. Percent population reduction due to treatment used the average of check plots 1 to 4, since post-spray egg-mass counts were not significantly correlated with pre-spray counts ($r=0.239$; $p=0.698$). Population reductions due to treatment were 76% and 80% for virus treatments at 5.0 L/ha and 2.5 L/ha, respectively, and 96% for the *B.t.k.* treatment. Virus treatment 1 and virus treatment 2 were both significantly different from the *B.t.k.* treatment ($p<0.05$; Kruskal-Wallis one-way analysis of variance nonparametric test).

Discussion

It was a cool spring and treatments were applied later than in previous years. Lake Huron had a cooling effect on Pinery Provincial Park and this was evident in the difference in cumulative

TABLE VI. Assessment of treatments on the gypsy moth in Pinery Provincial Park, 1994.

Treatment	Plot	% Virus infection May 24 - June 6 (n=50)	Pupae/m burlap trap (± SE)[a]	% Defoliation (± SE)[a]	Adjusted pre-spray E.M.[b]/ha (± SE)[a]	Post-spray E.M.[b]/ha (± SE)[a]	% Change[c] (± SE)[a]	Population reduction due to treatment[d]
Virus 1	1	8	3.1 ± 1.43	5.4 ± 1.19	11,030 ± 1,516	970 ± 310	-87.8 ± 3.7	48
	2	8	3.3 ± 0.99	24.9 ± 2.36	7,368 ± 792	105 ± 41	-98.8 ± 0.4	94
	3	4	7.7 ± 3.08	21.8 ± 1.94	13,728 ± 2,870	595 ± 122	-92.3 ± 2.0	68
	4	6	11.8 ± 3.12	21.8 ± 1.94	4,739 ± 442	415 ± 82	-91.7 ± 1.4	78
	5	6	3.4 ± 0.72	19.1 ± 1.64	7,730 ± 1,058	150 ± 62	-92.8 ± 0.7	92
	Mean	6.4	5.9 ± 1.70	18.6 ± 3.42	8,919 ± 1,563	447 ± 158	-93.8 ± 2.1	76
Virus 2	1	2	7.0 ± 1.53	17.5 ± 1.69	11,918 ± 2,205	640 ± 177	-92.8 ± 1.6	66
	2	4	9.0 ± 1.63	18.6 ± 1.66	2,848 ± 567	310 ± 76	-86.9 ± 3.2	83
	3	2	4.5 ± 0.53	19.6 ± 1.80	10,713 ± 1,127	295 ± 49	-96.5 ± 0.7	84
	4	0	9.1 ± 2.75	19.6 ± 1.53	6,726 ± 2,258	355 ± 76	-82.9 ± 3.2	81
	5	10	2.5 ± 0.36	19.8 ± 1.51	5,588 ± 780	275 ± 55	-94.0 ± 1.3	85
	Mean	3.6	6.4 ± 1.28	19.0 ± 0.43	7,450 ± 1,621	375 ± 68	-91.9 ± 1.7	80
B.t.k.[e]	1	0	5.4 ± 1.12	22.7 ± 1.96	1,224 ± 178	80 ± 24	-94.8 ± 1.3	96
	2	2	2.7 ± 1.03	17.5 ± 2.62	1,251 ± 228	30 ± 18	-98.1 ± 1.1	98
	3	6	6.4 ± 0.75	28.1 ± 1.83	4,582 ± 661	105 ± 29	-94.6 ± 1.9	94
	4	0	1.3 ± 0.33	6.5 ± 0.72	12,746 ± 1,082	35 ± 15	-99.7 ± 0.1	98
	5	0	7.3 ± 1.36	25.2 ± 2.66	7,281 ± 647	155 ± 39	-97.5 ± 0.7	92
	Mean	1.6	4.6 ± 1.13	25.2 ± 2.66	7,450 ± 2,154	81 ± 23	-96.9 ± 1.0	96

......continued

TABLE VI — continued.

Treatment	Plot	% Virus infection May 24 - June 6 (n=50)	Pupae/m burlap trap (± SE)[a]	% Defoliation (± SE)[a]	Adjusted pre-spray E.M.[b]/ha (± SE)[a]	Post-spray E.M.[b]/ha (± SE)[a]	% Change[c] (± SE)[a]	Population reduction due to treatment[d]
Check	1	4	42.5 ± 3.60	49.8 ± 3.59	2,249 ± 454	2,515 ± 289[g]	123.6 ± 51.5	-
	2	0	84.4 ± 2.93	73.7 ± 1.86	7,184 ± 1,078	1,745 ± 134	-17.8 ± 22.3	-
	3	0	33.1 ± 2.93	45.1 ± 2.89	5,704 ± 622	1,355 ± 100	-69.8 ± 4.5	-
	4	8	38.6 ± 3.85	44.9 ± 2.17	1,778 ± 232	1,811 ± 135[g]	48.6 ± 26.5[h]	-
	5[f]	8	16.2 ± 2.42	22.0 ± 1.52	10,899 ± 1,187	560 ± 95	-93.5 ± 1.3	-
	Mean	4.0	43.0 ± 11.28	47.1 ± 8.23	5,563 ± 1,680	1,598 ± 320	-7.8 ± 40.76	-

[a] SE = standard error

[b] E.M. = egg masses

[c] % change = mean of [(Post-spray - Pre-spray)/Pre-spray] x 100 among the 20 sample trees in each plot

[d] 100 x [1-(Treated post-spray/Check post-spray)] where Check post-spray is the overall average of the post-spray check values (averages = 1857, n = 4)

[e] *Bacillus thuringiensis* subsp. *kurstaki*

[f] Omitted from the calculations of population reduction due to treatment

[g] No significant difference in egg masses/ha between pre-spray and post-spray ($p>0.10$; paired Wilcoxon)

[h] No significant difference from zero ($p>0.05$; Wilcoxon)

temperature readings from towers 1 and 2 which were 2.5 and 0.5 km, respectively, from the lakeshore.

Both NPV treatments and the *B.t.k.* treatment had a significant impact on the gypsy moth population, both in terms of population reduction and foliage protection. The overwintering egg-mass mortality, which ranged from 15 to 85%, was a major factor in reducing the very high egg-mass densities found in some plots. Adjusted egg-mass densities were used in calculations to determine population reduction due to treatment. If successful treatments are evaluated on the basis of keeping defoliation below 40% and post-spray egg-mass densities below 1,250/ha, all the treated plots fell well below these figures. In 4 of the 5 check plots, defoliation exceeded 40% and post-spray egg-mass counts ranged from 1,355 to 2,515/ha. The population collapsed in check plot 5. This plot was eliminated from calculations of population reduction due to the treatments. There was a prescribed burn in 1993 in and around the area of check plot 5. Several mature oak trees, included in egg-mass counting plots, were affected and the leaves from these trees did not flush. Thus, plots had to be relocated after gypsy moth eggs had hatched. This is the principal reason that untreated check plot 5 was omitted from the data analysis. There was naturally occurring NPV throughout the area which is normal in any established gypsy moth outbreak. Pre-spray incidence of NPV infection in each plot ranged from 0 to 10% (n=50).

The 5.0 L/ha application was complicated by the fact that on the first application, plots had to be sprayed twice at 2.5 L/ha because a flow rate of 5.0 L/ha could not be achieved due to low temperatures and increased viscosity of Carrier 244. This is a problem that must be addressed before operational use of Carrier 244 is contemplated. An emitted volume of 5.0 L/ha has been used experimentally in Ontario for several years. Attempts to use lower volumes with different tank mixes have proved to be less effective. It is encouraging to note that results with 2.5 L/ha using Carrier 244 were as good as those at 5.0 L/ha. Carrier 244 costs about $2.50 U.S./L, so a reduction in volume rate provides a considerable cost saving, and increases the efficiency of spray aircraft in large scale operations.

Results from the *B.t.k.* application were outstanding with post-spray egg-mass densities ranging from 30 to 155/ha. It was intended to apply the *B.t.k.* in two applications of 30 BIU/ha, 3 to 7 days apart. However, the aircraft was urgently required elsewhere and the *B.t.k.* was applied at the maximum permitted label dosage in a single application. Obviously, single applications are preferable to double applications if adequate control can be achieved and, in this situation, the single application worked well. Single applications can result in poor control when egg hatch is extended over a long-period, such as in mountainous terrain. The situation in Pinery Provincial Park was flat terrain, but temperatures were cooler closer to the lakeshore. All the *B.t.k.* treated plots were about the same distance from the lake.

Spray deposit assessments indicated that coverage and penetration were good for both virus applications and the *B.t.k.* application. The two virus applications, employing volume rates of 5.0 and 2.5 L/ha, resulted in similar droplet densities which adds evidence for recommending the lower volume. Spray droplets were found largely on the upper leaf surfaces, as noted in 1993 virus spray trials (Payne *et al.* 1996). This, combined with the fact that early instar gypsy moth larvae feed mainly on the undersides of leaves, suggests that the targeting of these sprays may be improved by obtaining greater deposits on the undersides of leaves. This could probably be achieved using smaller droplets applied under turbulent conditions. These trials have proved that a tank mix of Disparvirus and Carrier 244 is a viable pest management option provided problems concerning the viscosity of Carrier 244 at low temperatures are rectified.

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AERIAL SPRAY TRIALS WITH NUCLEAR POLYHEDROSIS VIRUS AND *BACILLUS THURINGIENSIS* ON GYPSY MOTH (LEPIDOPTERA: LYMANTRIIDAE) IN 1994

II. IMPACT ONE YEAR AFTER APPLICATION

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Abstract

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Aerial spray trials were conducted in Pinery Provincial Park in 1994 using Disparvirus (nuclear polyhedrosis virus (NPV)) and Foray 48B *(Bacillus thuringiensis* subsp. *kurstaki)* to control gypsy moth, *Lymantria dispar* (L.). The virus was formulated in Novo Nordisk Carrier 244. Dosage was a double application of 5×10^{11} polyhedral inclusion bodies (PIB)/ha (total 10^{12} PIB/ha) and two application volumes were tested, 5.0 L/ha and 2.5 L/ha. Foray was applied as a single application of 50 billion international units (BIU) in 4.0 L/ha. Treatments were replicated on five 10 ha plots and a further five 10 ha plots were used as untreated check plots. Reduction in egg-mass numbers, foliage protection, and pupal counts were significantly lower in all treatments than in the untreated check plots.

The same plots were sampled in 1995 to determine the impact of the treatments one year after application. Samples of larvae collected weekly were diagnosed microscopically. Over the 7-week sampling period, 20.4% (n=1,251) were positive for NPV in plots treated with Disparvirus at 5.0 L/ha, 14.6% (n=1,529) in plots treated with Disparvirus at 2.5 L/ha, 8.0% (n=818) in plots treated with Foray 48B and 9.2% (n=1,577) in untreated check plots. Defoliation was negligible (<7%) in all treated and check plots. The mean pupal counts in burlap traps were slightly higher in the treated plots than in 1994, but fall egg-mass counts were very low in all treated and check plots, the highest being 415 egg-masses per ha in one of the untreated check plots. The gypsy moth population collapsed in Pinery Provincial Park in 1995; NPV found in all plots was obviously a contributing factor.

Introduction

Trials with gypsy moth, *Lymantria dispar* (L.), nuclear polyhedrosis virus (NPV) have been conducted every year from 1988 to 1994 with over 1,300 ha treated. The viral insecticide was either Disparvirus produced by Canadian Forest Service, Sault Ste. Marie or Gypchek® produced by the USDA Forest Service. Trials were undertaken in Pinery Provincial Park in 1994 to test the efficacy of Novo Nordisk Carrier 244 which was designed specifically with gypsy moth NPV applications in mind. A *Bacillus thuringiensis* subsp. *kurstaki* (*B.t.k.*) (Foray 48B) application was included as a positive control. Dosage of Disparvirus was a double application of 5 x 10^{11} polyhedral inclusion bodies (PIB)/ha (total 10^{12} PIB/ha) and two application volumes were tested, 5.0 L/ha (Virus 1) and 2.5 L/ha (Virus 2). Foray (*B.t.k.*) was applied as a single application of 50 billion international units (BIU) in 4.0 L/ha. Treatments were replicated on five 10 ha plots and a further five 10 ha plots used as untreated check plots. Reduction in egg-mass numbers, foliage protection and pupal counts were significantly lower in all treatments than in the untreated check plots (Cunningham *et al.* 1996).

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Follow-up studies were conducted in 1995 to determine the impact of the treatments one year following application and results are included in this report.

Materials and Methods

A description of the plots and treatments is reported by Cunningham *et al.* 1996. The same sub-plots for egg-mass surveys were used in 1995 as in 1994 and the 1994 fall egg-mass counts were used in calculations of population change. Additionally, 20 egg-masses were collected from each plot and placed individually in plastic petri dishes prior to hatching to determine overwintering mortality. Fall egg-mass counts were made in November 1995 and the same methods were used as in 1994. The same methods were also used to assess numbers of pupae in burlap traps and to estimate defoliation as in 1994.

A considerably more detailed examination of larvae was made in 1995 than in 1994 to determine the incidence of virus infection. An attempt was made to collect 50 larvae per week from each treated and each check plot over a 7-week period between egg hatch and the onset of pupation. If two people could not find 50 larvae in a period of 1 h, the search was terminated. Small larvae were collected from understorey vegetation and at mid-crown from foliage sampled with pole-pruners. Fourth instar and larger larvae were collected from burlap traps that were not located in the 0.01 ha sub-plots for the egg-mass surveys. Larvae were smeared on glass slides for microscopic diagnosis and stained using Naphthalene Black 12B as described by Cunningham *et al.* 1996. They were examined at X 1,000 under bright field and smears containing PIBs were scored as positive.

In the statistical analysis of data, the Mann-Whitney (Wilcoxon) rank sum test (Conover 1980) was used to compare two independent samples while the Kruskal-Wallis (1952) one-way analysis of variance was applied to the comparison of more than two independent samples. The BMDP computer program for nonparametric statistics (3S) was used to perform the calculations. In the statistical analysis of the egg-mass count data, 1994 and 1995 counts on individual 0.01 ha sub-plots were paired and this figure was used to calculate the percent population change.

Percent population reduction due to treatment used the average (229 egg-masses per ha) of all check plots (n=5). A regression approach was not used because of the weakness of the relationship between pre-spray and post-spray egg-mass densities.

Results

Incidence of virus infection

Over a 7-week period, a total of 5,175 larvae was examined from 20 plots. This was short of the target of 7,000 larvae because of problems in finding larvae, particularly in the first few

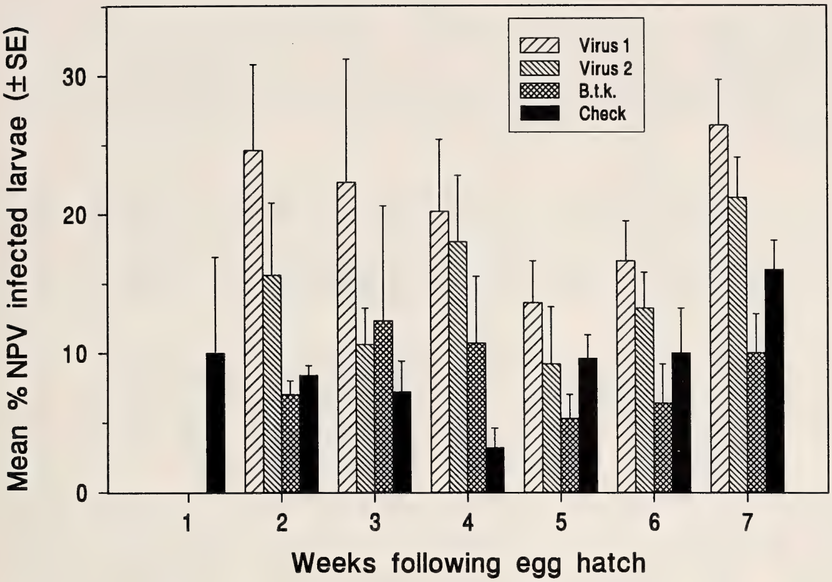

FIGURE 1. Incidence of nuclear polyhedrosis virus (NPV) in plots treated in Pinery Provincial Park, 1994.

weeks after hatching. Over the entire period, in the Disparvirus treatment at 5.0 L/ha (Virus 1), 20.4% (n=1,251) were positive for NPV, in the Disparvirus treatment at 2.5 L/ha (Virus 2), 14.6% (n=1,529) were positive, in the *B.t.k.* treatment, 8.0% (n=818) were positive and, in the untreated check plots, 9.2% (n=1,577) were positive. Levels of virus infection in the 3 treatments and the untreated check plots are shown in Figure 1 on a weekly basis and in Table I over the entire sampling period. The levels of virus infection were significantly higher in both virus treatments than levels in the untreated check plots (p<0.01). The incidence of virus infection in virus treatment 2 was not significantly different from the *B.t.k.* treated plots. Larvae from the *B.t.k.* treated plots were scarce and difficult to find, resulting in smaller samples than from the other treatments. Two peaks of NPV infection similar to that observed following a spray application are clearly evident in Figure 1 (Cunningham *et al.* 1991) with lowest incidence at 5 weeks post-emergence.

Pupae in burlap traps

Pupal counts are shown in Table I. In 1995, there were no statistically significant differences between the number of pupae/linear m of burlap trap in any of the treatments or untreated check plots. With the exception of the untreated check plots, the mean numbers of pupae in the treatments were slightly higher than those following the spray applications in 1994 (Cunningham *et al.* 1996). Mean pupal count from virus treatment 1 was 5.9 pupae/m in 1994 versus 9.9 in 1995, from virus treatment 2 was 6.4 in 1994 versus 13.1 in 1995, from the *B.t.k.* treatment was

TABLE I. Assessment of 1994 treatments on the gypsy moth population in Pinery Provincial Park, 1995.

Treatment	Plot	Pupae/m burlap trap (± SE)[a]	% Defoliation (± SE)[a]	% NPV[b] infected (± SE)[a]	E.M.[c]/ha Fall 1994 (± SE)[a]	E.M.[c]/ha Fall 1995 (± SE)[a]	% Change[d] (± SE)[a]	% Population reduction due to treatment carry-over[e]
Virus 1	1	6.7 ± 1.14	6.0 ± 0.27	16.2 ± 1.19	970 ± 310	5 ± 17	-92.8 ± 3.5	85
	2	4.7 ± 1.4	5.6 ± 0.19	20.0 ± 2.36	105 ± 41	30 ± 15[f]	-100.0 ± 0.0	87
	3	5.5 ± 0.67	6.3 ± 0.45	27.7 ± 1.94	595 ± 122	30 ± 13	-93.4 ± 3.6	87
	4	20.4 ± 2.02	5.1 ± 0.34	16.0 ± 1.94	415 ± 82	100 ± 40	-63.9 ± 17.2	56
	5	12.4 ± 1.29	3.2 ± 0.17	22.2 ± 1.64	150 ± 61	25 ± 12	-68.0 ± 21.1	89
	Mean	9.9 ± 2.94	5.2 ± 0.55	20.4 ± 3.42	447 ± 158	44 ± 16	-83.6 ± 7.4	81
Virus 2	1	2	7.0 ± 0.23	15.7 ± 1.69	640 ± 177	85 ± 35	-78.1 ± 10.3	63
	2	4	9.0 ± 0.32	16.8 ± 1.66	310 ± 76	55 ± 20	-77.0 ± 10.6	76
	3	2	4.5 ± 0.19	15.7 ± 1.80	295 ± 49	135 ± 47	-52.0 ± 17.7	41
	4	0	9.1 ± 0.23	13.7 ± 1.53	355 ± 76	50 ± 15	-84.4 ± 6.8	78
	5	10	2.5 ± 0.16	11.3 ± 1.51	275 ± 55	70 ± 50	-75.0 ± 20.8	69
	Mean	3.6	6.4 ± 0.48	14.6 ± 0.43	375 ± 68	79 ± 15	-73.3 ± 5.6	65
B.t.k.[g]	1	0	5.4 ± 0.21	7.2 ± 1.96	80 ± 24	195 ± 82[f]	+72.5 ± 137.9[h]	15
	2	2	2.7 ± 0.19	13.8 ± 2.62	30 ± 18	130 ± 55	-11.1 ± 58.8[h]	43
	3	6	6.4 ± 0.12	5.7 ± 1.83	105 ± 29	30 ± 13	-81.7 ± 10.7	87
	4	0	1.3 ± 0.18	4.3 ± 0.72	35 ± 15	100 ± 24	+40.0 ± 69.6[h]	56
	5	0	7.3 ± 0.33	9.0 ± 2.66	155 ± 39	105 ± 51[f]	+14.7 ± 75.1[h]	54
	Mean	1.6	4.6 ± 1.07	8.0 ± 2.66	81 ± 23	112 ± 27	+6.9 ± 26.1[h]	51

......continued

TABLE I — continued.

Treatment	Plot	Pupae/m burlap trap (± SE)[a]	% Defoliation (± SE)[a]	% NPV[b] infected (± SE)[a]	E.M.[c]/ha Fall 1994 (± SE)[a]	E.M.[c]/ha Fall 1995 (± SE)[a]	% Change[d] (± SE)[a]	% Population reduction due to treatment carry-over[e]
Untreated check	1	8.6 ± 0.71	6.7 ± 0.35	7.1 ± 1.74	2,515 ± 289	210 ± 82	-90.4 ± 3.9	-
	2	6.9 ± 1.65	7.0 ± 0.26	10.7 ± 1.89	1,745 ± 134	260 ± 71	-85.4 ± 3.8	-
	3	9.8 ± 1.05	6.7 ± 0.32	7.7 ± 3.01	1,355 ± 100	415 ± 102	-69.1 ± 6.2	-
	4	41.5 ± 4.61	5.4 ± 0.17	10.1 ± 4.58	1,811 ± 135	80 ± 24	-95.6 ± 1.4	-
	5	17.6 ± 1.58	4.9 ± 0.29	10.3 ± 2.52	560 ± 95	180 ± 61	-31.6 ± 34.4[h]	-
	Mean	18.9 ± 5.94	6.1 ± 0.41	9.2 ± 0.74	1,597 ± 320	229 ± 55	-74.4 ± 11.6	-

[a] SE = standard error

[b] NPV = nuclear polyhedrosis virus

[c] E.M. = egg masses

[d] % change = mean of [(Post-spray E.M./ha - Pre-spray E.M./ha)/Pre-spray E.M./ha] x 100 among the 20 sample trees in each plot

[e] 100 x [1-(1995 E.M./ha sprayed/1995 E.M./ha untreated)] where the untreated check plot count is the overall average of the 1995 values (average=229; n=5)

[f,h] In nearly all plots, the 1995 fall E.M. counts were significantly different from the 1994 fall E.M. counts (paired Wilcoxon) and the % change was significantly different from zero (Wilcoxon [$p<0.05$]). The [f] and [h] superscripts denote exceptions.

[g] *Bacillus thuringiensis* subsp. *kurstaki*

4.6 in 1994 versus 7.5 in 1995, and from the untreated check plots was 43.0 in 1994 versus 18.9 in 1995.

Defoliation estimates

Defoliation estimates are shown in Table I and defoliation in 1995 was negligible, so these figures were not analyzed statistically. The highest figure in any one plot was 7.0% in one of the untreated check plots.

Egg-mass counts

There was no detectable overwintering mortality of egg-masses in 1994/95 and all 400 egg-masses collected prior to hatching yielded large numbers of larvae in each petri dish.

Fall egg-mass counts in 1994 and in 1995 are given in Table I. With the exception of 5 plots, the percent change between the 1994 and 1995 fall egg-mass counts was statistically significant (paired Wilcoxon [$p<0.05$]). Four of these plots were treated with *B.t.k.* and had very low residual populations in the fall of 1994. A threshold that potentially causes unsightly defoliation and possible economic damage is 1,250 egg-masses per ha and only the untreated check plots at 1,597 in 1994 exceeded this threshold. Virus treatment 1 fell from a 1994 mean of 447 egg-masses per ha to 44 in 1995 which was calculated as a decrease of 83.6% based on individual plots. Virus treatment 2 fell from 375 to 79 for a calculated decrease of 73.3%. The *B.t.k.* treatment rose from 81 to 112 for a calculated increase of 6.9%. The untreated check plots fell from 1,597 to 229 for a calculated decrease of 74.4%.

Discussion

There are some unexplained anomalies in the results obtained in 1995. Pupal counts were higher than anticipated, defoliation much less than expected and egg-mass counts low in relation to the pupal counts. Plots were not visited between pupation in early August until fall egg-mass counts were made in November. There are four possible causes for high pupal mortality. They could have died as pupae due to NPV or a fungal disease, they could have been parasitized as larvae and died as pupae, or they could have been predated by mice. Considering the very high gypsy moth population in the Pinery Provincial Park in 1993, and its subsequent decline in 1994 and 1995, the parasites and predators would potentially have a major impact on the residual population.

Pre-spray samples of 50 larvae per plot were examined for NPV in 1994 and incidence ranged from 0 to 10% with an average of 3.9%. Sampling was not continued post-spray. It is highly probable that NPV spread throughout the park from the plots treated with virus in 1994 when first instar larvae were dispersed on silken threads by the wind in 1995. The incidence of NPV infection does not appear very high in 1995 (Fig. 1), but it must be pointed out that these low levels persisted over the 7-week period. Population counts at weekly intervals would be required to model the effect of the NPV in reducing the population and that is impossible to do with gypsy moth larvae. Insects positive for NPV infection in week 2 would certainly be dead by week 4, if not earlier, week 3 by week 5, and so on. Hence, one can speculate that an average of 21% infection will result in about 4-fold that amount in cumulative mortality.

The conclusion of this study, based on the results from untreated check plots, is that the gypsy moth population in Pinery Provincial Park would have collapsed in 1995 although this collapse was accelerated by the spray treatments in 1994. There was considerable overwintering mortality of egg-masses in the winter of 1993/4 and the population was in decline when the aerial spray trials were conducted. However, we were still able to demonstrate significant population reduction and foliage protection afforded by the two NPV treatments and one *B.t.k.* treatment compared to untreated check plots (Cunningham *et al.* 1996). This decline continued until the fall of 1995. Although the mean fall egg-mass numbers were highest in the untreated check plots at 229 egg-masses per ha, this is a very low population density.

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SYSTEMIC ACTIVITY OF NEEM SEED EXTRACTS CONTAINING AZADIRACHTIN IN PINE FOLIAGE FOR CONTROL OF THE PINE FALSE WEBWORM, *ACANTHOLYDA ERYTHROCEPHALA* (HYMENOPTERA: PAMPHILIIDAE)

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Abstract

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Laboratory bioassays using systemically-treated red pine, *Pinus resinosa*, branches and potted white pine, *P. strobus*, trees indicated that neem seed extracts containing azadirachtin (neem) were efficacious in controlling the pine false webworm, *Acantholyda erythrocephala*. Significant larval mortality on these branches occurred in a dose-dependent manner at concentrations greater than or equal to 32 µg AI per 200 ml of water. Population reduction reached 100% at 4,000 µg AI per 200 ml of water. Similarly, potted white pines treated with 150 and 250-ml soil drenches containing 0.1 g AI per tree of Neem EC in water resulted in significant population reductions. Timing of application influenced efficacy.

Preliminary field trials of systemic activity of a neem formulation against pine false webworm in 1995 were carried out using bole inoculations of Azatin EC at 0.05 g AI per tree. Even though the timing of this application was late, after egg hatch had begun, these trials indicated that population reduction of pine false webworm and foliage protection could be achieved under field conditions using systemic treatments. Treatments were carried out in 1996 on a larger sample of trees using earlier timing than 1995, before egg hatch. Applications on 16 May and 31 May of Neem EC resulted in excellent protection of 94 and 100% for previous year's foliage, respectively. Similarly, a 31 May application of Neemix 4.5 resulted in 96% protection of previous year's foliage. Thus, neem seed extracts applied systemically to pines under field conditions reduced larval numbers of pine false webworm and protected foliage. The use of neem formulations for systemic treatment of high value trees is discussed.

Introduction

Botanical insecticides based on extracts of the neem tree, *Azadirachta indica* A. Juss (Meliaceae), have proven to be extremely efficacious for control of a variety of pest insects (Schmutterer 1990). Although extracts contain several compounds with insecticidal activity, the

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principle active component in extracts is the tetranortriterpenoid, azadirachtin. This compound has been shown to affect phytophagous insects in a number of ways including direct toxicity; growth and developmental inhibition; and feeding, oviposition and settling deterrence (Schmutterer 1990). Neem seed extracts containing azadirachtin (neem) show considerable promise as safe alternatives to conventional insecticides in the control of forest insects (Helson 1992). Neem formulations have been shown to have a detrimental effect on forest insects such as spruce budworm, *Choristoneura fumiferana*, (Thomas *et al.* 1992) and gypsy moth, *Lymantria dispar*, (Shapiro *et al.* 1994) under laboratory conditions. Under field conditions, the birch leafminer, *Fenusa pusilla*, has been controlled by foliar applications of neem seed extracts (Larew *et al.* 1987). Foliar application of a neem formulation in a white spruce seed orchard also retarded spruce budworm development and provided significant foliage protection (Wanner and Kostyk 1995).

The systemic activity of azadirachtin in plant tissues has been known for some time (Gill and Lewis 1971). In addition to its activity as a foliar-applied insecticide, neem-based formulations have been shown to have systemic insecticidal activity in birch trees (Marion *et al.* 1990) and pine trees (Naumann *et al.* 1994). Naumann *et al.* (1994) demonstrated that a proprietary formulation of neem seed extract mitigated populations of mountain pine beetle larvae, *Dendroctonus ponderosae* Hopkins, in lodgepole pine, *Pinus contorta* Douglas, using applications of greater than 0.25 g AI per tree to axe frills on boles.

The pine false webworm, *Acantholyda erythrocephala* (L.) (Hymenoptera: Pamphiliidae) has become an increasingly significant pest of trees of the genus *Pinus* in Ontario and New York (Lyons 1995). Conventional insecticides will control this insect (Lyons *et al.* 1993) but concern about the safety of synthetic insecticides has prompted the search for safer alternatives such as botanical insecticides. Moreover, the cryptic behaviour of the larvae of this species (Lyons *et al.* 1993) makes it a suitable candidate for control by systemic insecticidal activity.

The purpose of this investigation was to determine if the pine false webworm could be effectively controlled with neem formulations through the use of systemic treatment of pine foliage under laboratory and field conditions. Specifically, we are reporting the effects on eggs and larvae of the pine false webworm of: 1) laboratory bioassays using red pine branch, *Pinus resinosa* Ait., cuttings that had absorbed neem formulation in water, 2) laboratory bioassays using potted white pine trees, *P. strobus* L. that had received soil drenches containing a neem formulation and 3) field trials with plantation-grown red pine trees that had a neem formulation inoculated into holes in their stems.

Materials and Methods

Red Pine Branch Bioassays. Eggs were obtained from field-collected gravid females of *A. erythrocephala* collected from Craighurst, Ontario. In the laboratory, several females were confined in lantern globe rearing containers with an excised red pine branch tip for egg deposition. The base of the rearing container consisted of a 350 ml ointment jar which was filled with distilled tap water. Two metal lids for the jars were riveted together top to top and a hole was drilled through the centre of the lids. One lid was screwed onto the ointment jar while the second lid served as the base for a lantern globe. The top of the lantern globe was covered with muslin to prevent the escape of the females. Branches collected from a red pine plantation near Sault Ste. Marie were cut to fit into the rearing containers. The excess foliage was removed from the stem of the branches, the bases of the branches were surface sterilized (Lyons *et al.* 1993) and the basal end of the branch was inserted through a hole in the lid of the jar. All rearing was conducted in a controlled environment room at 22-23°C, 70-80% RH, and 16L:8D photoperiod.

Females and egg-bearing branches were removed 24 h (day 0) after introduction into the rearing containers and the number of eggs were recorded. Basal ends of branches containing eggs were placed through a styrofoam plug into 250 ml olive jars containing 200 ml of tap water. Six days after oviposition, eggs were re-examined for viability, the basal tips of the branches were clipped to expose new wood and the water in the olive jars was replaced with 200 ml of distilled water. Branches were allocated to insecticide treatments and untreated controls such that each condition on a given day contained a similar number of eggs. Appropriate concentrations of Neem EC (Phero-Tech Inc., Delta, B.C.; 1.75% azadirachtin) were pipetted into each olive jar and the contents of the jar were agitated. Concentrations tested were: 1.28; 6.4; 32; 160; 800; 4,000; and 20,000 µg of azadirachtin in 200 ml of water.

Twelve days after oviposition the number of hatched eggs was recorded to determine the effects of Neem EC on egg hatch. The basal tips of the branches were clipped again at this time exposing fresh wood. Eighteen days after oviposition, branches were destructively sampled and the number of living larvae was recorded. Mortality of treated insects relative to mortality of control insects was corrected using Abbott's (1925) formula. Where corrected mortalities were greater than zero, χ^2 tests using SAS procedure FREQ (SAS Institute 1990) were performed to determine if the differences between treatment and control groups were significant.

Potted White Pine Bioassays. To produce eggs for potted-tree bioassays, gravid, field-collected females of *A. erythrocephala* were placed in a rearing cage with two approximately 0.5 m tall white pine trees potted in soil. Pots were 19.5 cm in diameter by 18 cm deep. After 24 h, trees containing eggs were removed from the cages and the number of eggs was recorded. Organic material on the surface of the soil was scraped off the tops of the pots.

For the early treatments, a 250 ml emulsion containing Neem EC (Phero-Tech Inc., Delta B.C.; 1.75% azadirachtin) formulation at 0.1 g active ingredient (AI) per tree was poured onto the soil on the day of oviposition. Trees received 250 ml of distilled water each day starting the day after treatment. Six days after treatment the number of viable eggs was determined by inspection. Twelve days after oviposition the number of hatched eggs was counted and at day 18 after oviposition the trees were destructively sampled and the number of living larvae was counted. For the late treatments, the same amount of active ingredient (0.1 g) was poured onto the soil surface of the pots, in 250 ml of water, six days after egg deposition, just prior to egg hatch. For some trees, 250 ml of water was added to the soil daily. For other trees, 150 ml of water was added daily. It was determined that very little run off from the pot occurred with 150 ml. Rearing for all treatments was undertaken in a controlled environment room under the same conditions described above. Data analysis was the same as described above.

Red Pine Field Trials. Field trials were conducted in a red pine plantation at Sprucedale, Ontario in 1995 and 1996. For a description of the plantation see Lyons *et al.* (1993). In 1995, thirty trees were selected for treatment. Half the trees were randomly assigned to an Azatin EC (AgriDyne Technologies Inc., Salt Lake City, UT; 3% azadirachtin) treated group and half were assigned to a treated (holes drilled in bole) control group. Trees were treated on 15 June 1995. On the same day, 60 branches from throughout the treatment area were examined to determine the proportion of eggs that had hatched.

In 1996, 150 trees were selected for treatment from various locations within the plantation. Trees were randomly assigned to one of the following five treatments: 1) early control; 2) early Neem EC (Neem International Enterprises Inc., Surrey, B.C.; 2% azadirachtin); 3) late control; 4) late Neem EC and 5) late Neemix 4.5® (W.R. Grace & Co.-Conn., Columbia, MD; 4.5% azadirachtin). Trees were treated on 16 May (early) and 31 May (late) 1996. At least three untreated trees separated experimental trees in both years. Heights of all experimental trees were measured to the nearest 10 cm. Mean tree heights for each treatment within a year were compared by analysis of variance followed by Tukey's studentized range test using SAS procedure GLM (SAS Institute 1990).

Trees were treated by bole inoculation. Two holes, approximately 1 cm in diameter (5/16" drill bit) were drilled diagonally downward at about a 60° angle into the stem of all trees on opposite sides near the base (treated and control) using a Makita 6095D cordless drill. The depths of the holes in 1995 were 1.5 cm while in 1996 the holes were drilled to 2.0 cm. For the Azatin EC treated trees in 1995, and the Neem EC and Neemix 4.5 treated trees in 1996, 0.83 ml, 1.25 ml and 0.56 ml of the formulations, respectively, were pipetted into each hole to give a total of 0.05 g azadirachtin per tree.

An upper and a lower branch were selected on each tree, randomly by cardinal direction, and marked with flagging tape. On 8 June 1995 and 4 June 1996, the number of eggs on each of these branches was counted. If the number of eggs was greater than 20, the number of eggs was culled down to 20. On 29 June 1995 and 3 July 1996, these same branches were revisited and the number of larvae was counted by destructively sampling the branches. Population reduction (PR) was calculated from the following:

$$PR(\%) = 100 \left[1 - \frac{larvae}{eggs} \right]$$

where larvae = the post-treatment number of larvae on a branch tip and eggs = the post-treatment number of eggs (Lyons *et al.* 1993). Mean population reductions for all treatments, within a year, were compared by analysis of variance followed by Tukey's studentized range test, after arcsine square root transformation of the data, using SAS procedure GLM (SAS Institute 1990). Within each treatment, mean population reductions for upper and lower branches were compared by means of *t*-tests after arcsine square-root transformation of the data using SAS procedure TTEST (SAS Institute 1990).

Defoliation of previous year's and current year's foliage was estimated subjectively by one experienced technician in increments of 10% on 17 August 1995 and 9 August 1996 after larval development was completed. Corrected foliage protection (FP) was calculated from the following:

$$FP(\%) = 100 \left[\frac{x - y}{x} \right]$$

where x = mean defoliation of untreated trees and y = mean defoliation of treated trees (Lyons *et al.* 1993). Mean defoliation of treated trees was compared with defoliation of control trees by analysis of variance and Tukey's multiple range test using SAS procedure GLM (SAS Institute 1990) after arcsine square-root transformation of the data. Webs on marked branches were categorized in 1996 as either: 1) large — evidence of frass production and larval feeding beyond first instar; 2) small — evidence of first instar larval feeding and frass production only; or 3) none — no evidence of feeding or frass production.

Results and Discussion

Red Pine Branch Bioassays. There were no significant differences in hatch, between eggs on red pine branches treated systemically with neem and those on water-treated control branches, at all concentrations tested (Table I). Conversely, corrected larval mortality of the pine false

TABLE I. The effects of systemic treatment of red pine, *Pinus resinosa*, branches with Neem EC on egg hatch of the pine false webworm, *Acantholyda erythrocephala*.

Conc. μg AI per 200 ml	Number of eggs				Mortality[a] (%)	χ^2	P^b
	Control		Treatment				
	Alive	Dead	Alive	Dead			
1.28	69	3	66	2	0.0	-	-
6.4	69	3	73	4	1.1	0.09	0.767
32	137	28	132	40	7.6	2.07	0.151
160	68	25	80	21	0.0	-	-
800	334	69	332	78	2.3	0.50	0.481
4,000	266	44	256	39	0.0	-	-
20,000	266	44	256	45	0.9	0.70	0.791

[a] Corrected using Abbott's (1925) formula

[b] Probability that the control and treatment are not significantly different for corrected mortality greater than 0.

webworm reached 100% at the highest concentrations of azadirachtin tested (i.e., 4,000 and 20,000 µg AI per 200 ml) and declined in a dose-dependent manner at lower doses (Table II). The lowest azadirachtin concentration that resulted in significant mortality between treated and control branches was 32 µg AI per 200 ml which produced a corrected mortality of 68.1%. Lower concentrations of 1.28 and 6.4 µg AI per 200 ml did not result in significant mortality.

These bioassays demonstrate that neem can act systemically to control larvae of the pine false webworm. Larvae feeding on the needles received lethal doses of the insecticide from within the consumed needles. Eggs of the pine false webworm are in intimate contact with the vascular system of the host tree and require water from the host to swell and develop (Schwerdtfeger 1941). However, the developing embryos in the eggs were not affected by concentrations that caused significant mortality in feeding larvae. It is possible that the active ingredient did not reach the eggs soon enough to cause mortality but it is much more likely that the developing embryos are not susceptible to the active ingredient or that the chorion of the egg was impervious to penetration by the active ingredient.

Potted White Pine Bioassays. Neither early nor late treatments of potted white pine trees with Neem EC resulted in significant reductions in egg hatch of the pine false webworm (Table III). However, larvae of the pine false webworm experienced significant mortality (Table IV) while feeding on foliage of potted white pines that had been treated systemically by soil drenching with Neem EC in water. At the same volume of added water (i.e. 250 ml) the early treatment (i.e., following egg deposition) resulted in much higher corrected mortality than did the late treatment trees (i.e., just prior to egg hatch). It is possible that following the later treatment, the active ingredient did not have enough time to reach the feeding sites in high enough concentration to result in high mortality. By reducing the volume of water added to the trees to 150 ml/day, the active ingredient was more concentrated in the water absorbed by the trees and more quickly reached the feeding sites in high enough concentration to cause 100% mortality, even with the later treatment date (Table IV). In addition, less material was lost due to run off (i.e., leaching). Soil

TABLE II. The effects of systemic treatment of red pine, *Pinus resinosa*, branches with Neem EC on larval mortality of the pine false webworm, *Acantholyda erythrocephala*.

Conc. μg AI per 200 ml	Number of larvae: Control		Treatment		Mortality[a] (%)	χ^2	P^b
	Alive	Dead	Alive	Dead			
1.28	44	25	54	12	0.0	-	-
6.4	44	25	45	28	3.3	0.068	0.794
32	101	36	31	101	68.1	67.89	<0.001
160	57	11	5	75	92.5	90.87	<0.001
800	258	76	1	331	99.6	414.78	<0.001
4,000	201	65	0	256	100.0	314.57	<0.001
20,000	201	65	0	256	100.0	314.57	<0.001

[a] Corrected using Abbott's (1925) formula

[b] Probability that the control and treatment are not significantly different for corrected mortality greater than 0.

drenches using neem formulations may have a role in protecting potted trees from insect damage under green house conditions.

Red Pine Field Trials. The results of bole inoculations of plantation-grown red pines with neem formulations are shown in Table V. The proportion of eggs that had hatched when the trees were treated on 15 June 1995 was 0.474. No eggs had hatched by 4 June in 1996. In 1995, defoliation of neem-treated trees was significantly lower than in control trees for both previous year's and current year's foliage. Even after systemic treatment with neem, the trees did sustain significant defoliation. Corrected protection percentages for previous year's foliage and current year's foliage on treated trees in 1995 were 53 and 64%, respectively. Pine false webworm con-

TABLE III. The effects of systemic treatment of potted white pine, *Pinus strobus*, trees with Neem EC on egg hatch of the pine false webworm, *Acantholyda erythrocephala*.

Treatment [timing/ volume (ml)]	Number of eggs: Control		Treatment		Mortality[a] (%)	χ^2	P^b
	Alive	Dead	Alive	Dead			
early/250	372	15	225	15	2.5	1.83	0.176
late/250	372	15	381	3	0.0	-	-
late/150	108	8	150	1	0.0	-	-

[a] Corrected using Abbott's (1925) formula

[b] Probability that the control and treatment are not significantly different for corrected mortality greater than 0.

TABLE IV. The effects of systemic treatment of potted white pine, *Pinus strobus*, trees with Neem EC on larval mortality of the pine false webworm, *Acantholyda erythrocephala*.

Treatment [timing/ volume(ml)]	Number of larvae				Mortality[a] (%)	χ^2	P^b
	Control		Treatment				
	Alive	Dead	Alive	Dead			
early/250	324	48	13	212	93.4	377.12	<0.001
late/250	324	48	171	210	48.5	148.93	<0.001
late/150	87	21	0	150	100.0	182.31	<0.001

[a] Corrected using Abbott's (1925) formula

[b] Probability that the control and treatment are not significantly different for corrected mortality greater than 0.

centrates its feeding activity to previous year's foliage unless this foliage becomes entirely consumed (Lyons 1995). Therefore, damage to the current year's expanding foliage only occurs after high larval feeding pressure and has developmental consequences for the tree in the following year. Reduction of feeding in previous year's foliage therefore also protects the new foliage. Population reduction in upper and lower branches of azadirachtin-treated trees in 1995 was significantly greater than the population reduction observed in the control trees. Thus, neem was efficacious in reducing larval numbers of the pine false webworm via systemic activity.

Mean defoliation of azadirachtin-treated trees in 1996 approximated 0% and was significantly different from the defoliation of untreated trees (Table V). Mean defoliation was not significantly different for any of three azadirachtin treatments for either previous year's or current year's foliage. Corrected protection percentages for previous year's foliage in 1996 for Neem EC (early), Neem EC (late) and Neemix 4.5 (late) were 95, 100 and 96%, respectively. All three treatments resulted in 100% corrected protection for current year's foliage. Similarly, all azadirachtin-based treatments resulted in 88.9% or greater population reduction of the pine false webworm and were not significantly different from each other. Timing of both early and late treatments was equally efficacious and had allowed enough time for the active ingredients to reach the feeding sites by the time eggs hatched. The two azadirachtin formulations, Neem EC and Neemix 4.5, were also equally efficacious in controlling the pine false webworm systemically. The systemic treatment on 15 June 1995 was late in terms of the phenology of the pine false webworm compared with the treatments on 16 and 31 May 1996 and may have been responsible for the lower efficacy of the treatment in 1995. A suitable amount of time prior to larval hatch is required to prevent most feeding damage.

There were no significant differences (*t*-test, $P>0.05$) in the levels of population reduction between the upper and lower branches in any of the treatments in either year. This suggests that the active mortality agent became distributed throughout the vertical strata of the trees. Within a specific year there were no significant differences in tree heights between treatments (Table V).

Control trees had a preponderance of large webs when compared with the treated trees (Table VI). Large webs were defined as webs that contained evidence of large frass pellets, webbing and significant feeding damage. Newly eclosed larvae feed on the edges of the needles and spin a small amount of silk at the base of the needle fascicle (Lyons 1995). Small webs were defined as those

TABLE V. Effects of systemic bole inoculations of neem formulations into red pines (*Pinus resinosa*) growing in a plantation at Sprucedale, Ontario on pine false webworm (*Acantholyda erythrocephala*).

Year	Treatment	Number of trees	Mean (SE)[a] tree height (m)	Mean (SE) defoliation (%)[b]		Mean (SE) population reduction (%)[b]		
				Previous year's foliage	Current year's foliage	Upper branches	Lower branches	Both branches[c]
1995	control	15	3.1(0.09)a	60(6.2)a	11(2.6)a	61.1(7.05)a	57.7(9.17)a	59.4(5.69)a
	Azatin EC	15	3.1(0.07)a	28(4.0)b	4(1.3)b	81.9(6.75)b	84.0(7.77)b	83.0(5.06)b
1996	control-early	28	2.8(0.10)a	55(5.7)a	11(2.6)a	57.6(7.11)a	69.8(6.51)a	63.6(4.84)a
	Neem EC-early	25	3.0(0.11)a	3(1.4)b	0(0.0)b	88.9(5.80)bc	95.0(4.08)b	91.9(3.54)b
	control-late	24	3.0(0.12)a	52(6.3)a	14(4.4)a	78.1(5.49)ab	78.7(5.69)a	78.4(3.91)a
	Neem-EC-late	27	3.1(0.12)a	0(0.4)b	0(0.0)b	96.3(3.70)c	100.0(0.0)b	98.1(1.85)b
	Neemix 4.5-late	28	3.1(0.12)a	2(0.7)b	0(0.0)b	99.5(0.51)c	95.3(3.68)b	97.4(1.86)b

[a] Means within a year and column followed by the same letter are not significantly different [ANOVA and Tukey's studentized range test (Proc GLM, SAS Institute 1990)]

[b] Means followed by the same letter within a year, after arcsine square-root transformation of the data, are not significantly different [ANOVA and Tukey's studentized range test (Proc GLM, SAS Institute 1990)]

[c] Means population reduction (%) between upper and lower branches is not significantly different [*t*-test (Proc TTEST, SAS Institute 1990)]

TABLE VI. Pine false webworm (*Acantholyda erythrocephala*) web sizes on red pine (*Pinus resinosa*) branches treated systemically with azadirachtin-based insecticides in a plantation at Sprucedale, Ontario in 1996.

Treatment	Web size		
	Large	Small	None
control — early	50	4	0
Neem EC — early	4	41	4
control — late	44	4	0
Neem EC — late	0	48	5
Neemix 4.5 — late	3	51	2

that only contained frass pellets from newly-eclosed larvae and their feeding damage. These were branch tips where the larvae eclosed from the eggs and began to feed but failed to become established. The majority of treated trees had web sizes that fell into this category. 'None' indicated that the branches contained eggs but there was no evidence of larval activity. Only a small number of treated trees contained branches in this category. The eggs may or may not have hatched. These data suggest that very few larvae on treated trees became established on the branches. By the time the post-spray population assessment was conducted, many of the control tree branches had been totally defoliated. Many larvae would have left the branches to seek other sources of foliage or would have died due to conspecific competition. Thus, observed differences in population reduction estimates (Table V) between treated and control trees would be very conservative. Conversely, these web data (Table VI) indicate that on most control branches larvae became established and formed large webs.

The short residual life of azadirachtin-based insecticides when applied as a foliar application (Sundaram and Curry 1994), although attractive from an environmental perspective, presents a significant limitation from a forest pest management point of view. This limitation may be overcome by applying these formulations systemically into foliage. The ability of birches (Marion *et al.* 1990) and aspens (Sundaram *et al.* 1995) to translocate azadirachtin-based insecticide from the site of inoculation to arthropod feeding sites in foliage has been demonstrated previously. Naumann *et al.* (1994) have shown that similar systemic translocation of azadirachtin controlled a phloem-feeding insect, the mountain pine beetle. Herein, we have demonstrated that this mode of treatment with neem formulations provides effective control of the pine false webworm feeding on pine foliage. The amount of insecticide required to effect control was comparable to the amount required for the same degree of efficacy via foliar application (unpublished data). The cost of azadirachtin-based insecticide formulations is considerably higher than most conventional insecticide formulations but their low impact on most non-target organisms (Schmutterer 1990) makes them an attractive alternative. This is even more so with systemic applications of neem which not only further reduces any impact to non-targets but also reduces hazards to handlers because of its low mammalian toxicity. The treatment window is also much larger for systemic applications. However, bole inoculations are labour intensive. It takes considerably more time to drill holes in trees and dispense insecticide than it does to apply the material using spray apparatus. Further research is required to help streamline the treatment process and make it more cost-effective. The use of systemic inoculation of pine to control pine false webworm may be suitable for the treatment of high value trees such as landscape or seed-orchard plantings.

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NOTES ON NATIVE PARASITOIDS AND PREDATORS OF THE LARGER PINE SHOOT BEETLE, *TOMICUS PINIPERDA* (LINNAEUS) IN THE NIAGARA REGION OF CANADA (COLEOPTERA: SCOLYTIDAE)

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Abstract

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The species of parasitoids and predators found associated with *Tomicus piniperda* (Linnaeus) in a single, infested Scots pine (*Pinus sylvestris*) in Niagara Falls, Ontario, Canada are recorded. The following species are noted: Hymenoptera: Braconidae— *Coeloides pissodis* (Ashmead), *Spathius* sp,; Pteromalidae—*Dinotiscus dendroctoni* (Ashmead), *Rhopalicus tutela* (Walker), *Roptrocerus xylophagorum* (Ratzeburg); Eupelmidae— *Eupelmus* sp.; Eurytomidae— *Eurytoma* sp. Coleoptera: Histeridae— *Cylistix gracilis* (LeConte); Tenebrionidae— *Corticeus praetermissus* (Fall). Diptera: Dolichopidae— *Medetera signaticornis* Loew, *M. pinicola* Kowarz. The importance of understanding the role of native parasitoids and predators in the management of the introduced *T. piniperda* is discussed.

Introduction

The larger pine shoot beetle, *Tomicus piniperda* (Linnaeus), is a serious pest of pines, *Pinus* spp., throughout Europe and Asia (Bakke 1968). It is widely distributed throughout the coniferous forest regions of Europe and Asia, and is also known from Great Britain, Northern Ireland, Cyprus, North Africa, Madeira Islands, and has been introduced into the Philippine Islands (Wood and Bright 1992). Its principal host in Europe is Scots pine, *Pinus sylvestris*, but it also infests other species of pines, as well as *Larix* species, *Picea* species and *Pseudotsuga menziesii*, although the latter three genera of trees suffer much less damage (Bakke 1968).

Specimens of *T. piniperda* have been intercepted several times at United States seaports. Until recently, however, a breeding population in the United States has not been detected. During routine sampling of a Christmas tree plantation near Cleveland, Ohio, in July, 1992, an established population of *T. piniperda* was found. Subsequent surveys revealed that the species was widely distributed south of the Great Lakes from near Chicago, Illinois to Buffalo, New York (Haack *et al.* 1993). In May, 1993, populations of the species were found in the Niagara region (Niagara Falls, Fort Erie/Cairns, Bowen Road, and Dunnville) of southern Ontario. As of the end of 1995, *T. piniperda* was found in 147 counties in eight U.S. states and in 13 counties in Ontario (Haack 1996).

There is a large body of information concerning this species in Europe and Asia (see references in Wood and Bright 1987, 1992). The following brief outline was extracted from Bakke 1968. In Europe, overwintering adults emerge early in the spring, when daily temperatures exceed 10–12°C and the mean daily temperature is about 7–8°C. Adults are attracted to felled, wind thrown or weakened host trees with thick bark. Mating occurs on the host plant. The adults are attracted by chemicals released by susceptible trees such as monoterpenes, alpha-pinene, 3-carene and terpinolene. No sex pheromone has been reported. The adults form monogamous pairs to construct the brood galleries. Because bark more than 4–5 mm thick is required for gallery construction, attacks are most often in the basal part of the bole, but may occur higher on older trees. On a fallen log, galleries are concentrated on the upper sides of the bole. The female excavates a longitudinal gallery under the bark on the phloem-cambial layer; the male pushes the boring dust out of the entrance hole (Davies and King 1977). Eggs are laid in niches on both sides of the gallery. The eggs hatch from one to three weeks later and the larvae feed in individual galleries moving away from the parent gallery. Pupation occurs at the end of the larval mines in the bark. At a constant temperature of 12°C, a complete generation takes 99 days, at 22°C, 33 days and at 27°C, 21 days. The time required for the completion of a generation in Canada has not been investigated. Because *T. piniperda* is univoltine, the total time required for gallery construction, brood development and emergence in Canada is probably more than two months.

Young adults which have just emerged from the host tree, and parent adults that have finished producing their first brood, fly to the crowns of living, healthy pine trees and bore into live, lateral shoots from about June onward, to feed in order to mature their reproductive system. A second brood may be developed by these parent adults (Sadof *et al.* 1994). It is this shoot-feeding habit that causes the damage attributed to this species. Attacked shoots generally bend near the point where the beetles entered, turn yellow to red, eventually break off, and fall to the ground. During this period of feeding, each adult may destroy 1–6 shoots (Haack *et al.* 1993).

Very little has been recorded on the biology of this species in North America. In the Lake States (and probably Canada), adults leave the shoots about the time of the first frost in October and November and enter the thick bark at the base of trees for overwintering (Haack and Kucera 1993). Sometimes individuals may move back into the trunks to construct new galleries and lay a second batch of eggs. The adults of this second brood usually emerge late in the summer (Thomas and Dixon 1992).

The shoots fed upon by the adults of this species are killed by the tunneling activities. Trees that are repeatedly attacked grow more slowly and may become more susceptible to attacks by other bark beetles. Infested trees may become distorted in growth form. The activities of this species will affect Christmas tree plantings, urban plantings, nursery production, and timber production. Intra- and intercontinental trade in forestry products has already been adversely affected.

The purpose of this paper is to document the occurrence of several parasites and predators associated with *T. piniperda* in the Niagara region of Ontario.

Materials and Methods

Two 60 cm bolts from the bole of a heavily infested 5–6 m tall Scots pine from the Niagara Parks Commission area in Niagara Falls, Ontario were placed in secure rearing cages in Ottawa. The infested tree was in a shelterbelt planting on the western edge of the park. The cause of death of the tree was not determined. The emerging parasitoids, predators and bark beetles were collected daily. The Hymenoptera and Diptera were mounted and identified by members of the Crop Protection Program (see acknowledgements below), Research Branch, Agriculture and Agri-Food Canada. The Coleoptera were identified by the author.

Results

No bark beetle species other than adults of *T. piniperda* emerged from the samples. The following parasitoids or predators emerged from *T. piniperda* infested logs:

HYMENOPTERA

Braconidae

Coeloides pissodis (Ashmead). This is a common species over most of eastern North America. Reared specimens are reported from various weevils and bark beetles in pines; the most frequently reported hosts are *Pissodes approximatus* Hopkins, *P. nemorensis* Germar, *P. strobi* (Peck) (Curculionidae), and *Dendroctonus frontalis* Zimmermann, *Ips calligraphus* (Germar), and *I. grandicollis* (Eichhoff) (Scolytidae) (Mason 1978; Marsh 1979).

Spathius sp. This is a cosmopolitan genus of Braconidae with 21 described North American species which, with few exceptions, are ectoparasitoids of wood-boring Coleoptera, predominantly Scolytidae (Matthews 1970).

Pteromalidae

Dinotiscus dendroctoni (Ashmead). This species is evidently widely distributed across North America. Recorded hosts include several species of *Dendroctonus*, *Ips*, and *Polygraphus* (Scolytidae) plus subcortical weevils such as *Cylindrocopterus furnissi* Buchanan (Grissell 1983).

Rhopalicus tutela (Walker). This species is known from the northeastern United States to Quebec and Ontario, and is widely distributed in Europe and Japan. In North America, the reported hosts are *Ips pini* (Say) and *Pissodes strobi* (Peck). In Europe the species is reported from numerous species of Scolytidae as well as 3 species of *Pissodes*. In Japan the species is commonly found on trunks of pine and larch infested by bark beetles (Grissell 1983).

Roptrocerus xylophagorum (Ratzeburg). This is a common species throughout most of North America; it is recorded as an ectoparasite from a number of bark beetles (Bushing 1965; Grissell 1979). This species is occasionally placed in the family Torymidae (Grissell 1979).

Eupelmidae

Eupelmus sp. This genus contains about 38 species in North America (Burks 1979a). This unidentified species is likely a hyperparasite of a species of pteromalid.

Eurytomidae

Eurytoma sp. Seven species of this genus are listed as parasitoids of various species of bark beetles (Bushing 1965). Most species are primary or secondary parasitoids and some are phytophagous (Burks 1979b). When the genus is better known more species will likely be found to occur as parasitoids of subcortical weevils and bark beetles.

COLEOPTERA

Histeridae

Cylistix gracilis (LeConte). Nothing is recorded on the life history or habits of this species. Histerids commonly found associated with scolytids under the bark of dead and dying trees are almost certainly predators.

Tenebrionidae

Corticeus praetermissus (Fall). This common, boreal, predaceous species occurs throughout North America, except in the eastern and southeastern regions of the United States. Specimens have been found in a wide variety of coniferous trees in association with species of *Ips* and *Dendroctonus* (Triplehorn 1990).

DIPTERA

Dolichopodidae

Medetera signaticornis Loew. This holarctic, circumboreal species occurs in Europe through Siberia to Japan, Alaska, across Canada to the Maritime provinces, south into the northeastern United States and to Oregon and Idaho. The species is a predator and is a common associate of a variety of scolytids in spruce and pines (Bickel 1985).

M. pinicola Kowarz. This holarctic species is recorded from Europe west of the Urals and in North America from British Columbia to Quebec, south to northern Georgia and Arizona. This species is a predator and is commonly found in association with a variety of scolytids in spruce, pines, and Douglas-fir (Bickel 1985).

Discussion

It is possible that some of the associates recorded above may have emerged from some other species of insect present in the caged logs; however, the only species of bark beetle to emerge from the logs was *T. piniperda*. No specimens of Curculionidae, Cerambycidae, Buprestidae or any other possible host insect were recovered, and when the logs were debarked at the conclusion of emergence, no galleries of Cerambycidae, Buprestidae or other species of Scolytidae were observed.

Most of the parasitoids and predators listed above are habitat-specific, not host-specific; a few (e.g. *Eupelmus*) are suspected to be hyperparasitoids. For the majority of species listed, any bark beetle (or perhaps any other insect of sufficient size) encountered under the bark would probably serve as a host.

It has been suggested that biological control agents could or should be introduced to control or manage *T. piniperda* populations in North America. In my view, before any parasitoids and/or predators are introduced, the role of native parasitoids and predators associated with *T. piniperda* should be thoroughly investigated and assessed.

The question of competitive displacement must also be addressed. No information is presently available on the possible effects of introduced parasitoids on the populations of native parasitoids of *T. piniperda*.

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BEHAVIOUR OF JACK PINE BUDWORM (LEPIDOPTERA: TORTRICIDAE) ON VEGETATIVE OR POLLEN-CONE SHOOTS

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Abstract *Proc. ent. Soc. Ont.* 127: 63–66

The behaviour of individual newly emerged second-instar jack pine budworm (*Choristoneura pinus*) was observed on vegetative or pollen-cone shoots of jack pine (*Pinus banksiana*). Eight times more budworm established feeding sites in pollen-cone buds than in vegetative buds. Twice as many budworm dispersed from vegetative shoots than from pollen-cone shoots.

The jack pine budworm (*Choristoneura pinus* Freeman) is a serious defoliator of jack pine (*Pinus banksiana* Lamb.) stands throughout the Great Lakes region of North America. The jack pine budworm is univoltine. Moths mate in early August and lay eggs in masses on jack pine foliage. These eggs hatch within 2 weeks and the neonate larvae crawl under bark scales and spin a silken hibernaculum. The larvae then moult to second instars and overwinter in this stage. Larvae emerge in the spring and seek suitable feeding sites on current-year growth of the host tree. During this critical period, larvae are commonly found in the pollen cones of the host tree (Graham 1935; Lejeune and Black 1950; Foltz *et al.* 1972; Batzer and Jennings 1980; Clancy *et al.* 1980). Nealis and Lomic (1994) have shown recently that this association with pollen cones has a significant influence on the population ecology of the jack pine budworm.

This paper examines the behaviour of individual second-instar jack pine budworm larvae immediately following their emergence from overwintering hibernacula. The objective of this study was to analyze the behaviour of individuals leading to the aggregation of larvae on the pollen cones of the host tree.

Second-instar larvae for the experiment were obtained from budworm infestations in northeastern Ontario. Branches harbouring overwintering budworm were collected in April before natural emergence of the jack pine budworm and kept at 4°C (Nealis and Lomic 1994). Freshly-emerged budworm were obtained by the method used by Nealis and Lysyk (1988). Branches were cut up, wrapped in paper towelling and hung in an emergence chamber at 20°C. Emerging larvae

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were retrieved each morning and held at 10°C until used in the experiment. All experiments were conducted between 09:00 and 12:00 EST. Only larvae emerging on the day of the experiment were used.

The jack pine vegetative and pollen-cone shoots used in the experiment were collected near Sault Ste-Marie Ontario on 3 June 1993 and kept at 4°C until used. Both types of shoots had reached a stage of development that was acceptable as feeding sites for larvae as determined by a bioassay in an experiment that ran concurrently with this study (Nealis and Lomic 1994). The experimental arena consisted of a single vegetative or pollen-cone bud followed by 2 cm of 1-year-old foliage inserted through a styrofoam plug in order to keep the shoot upright. One budworm was placed at the bottom of each shoot and observed for 30 minutes. Each observer watched three budworm at a time. A new shoot was used for each budworm observed. A total of 125 budworm were observed and their behaviour was scored in two categories. First, the location of the budworm after 30 minutes was scored as: established, if the budworm was found in the bud; on the surface of the bud; on the previous year's foliage; not found or other (e.g. on the styrofoam). The second category was the behaviour of the budworm during the experiment. The budworm were scored as: dispersed, if the budworm fell off the shoot or left the bud after having walked onto it; and tip of the bud, if the budworm was observed at the tip of the bud.

The data were organized into a two-way contingency table and analyzed using a Model II test of independence with G as the test statistic (Sokal and Rohlf 1981). The 19 larvae that were not found at the end of the 30 minutes were eliminated from the analysis. This resulted in a comparison of 53 larvae observed on pollen-cone shoots and 53 larvae observed on vegetative shoots. There was no dependence detected between the number of larvae not found on vegetative and pollen-cone shoots (G=0.40, DF=1, p=0.53).

The location of the budworm at the end of 30 minutes depended on the type of shoot (pollen cone or vegetative) on which the budworm was placed ($p<0.05$) (Fig. 1). After 30 minutes, 8 times more larvae had established in pollen-cone buds than in vegetative buds (G=43.18, DF=1, $p<0.001$). Larvae on shoots with vegetative buds rarely established in those buds and 2.5 times more larvae provided with vegetative buds were found on the old foliage than were larvae provided with pollen cones (G=9.83, DF=1, p=0.002). When found on a bud, larvae were three times more likely to be on the surface of the vegetative buds than on the surface of the pollen-cone buds (G=5.56, DF=1, p=0.02).

The results of the budworm behaviour during the experiment are shown in Figure 2. Twice as many budworm dispersed from vegetative shoots than dispersed from pollen-cone shoots (G=8.66, DF=1, p=0.003). More budworm went to the tip of the bud on vegetative shoots than went to the tip of the bud on pollen-cone shoots (G=2.98, DF=1, p=0.086). This position was usually a precursor to subsequent dispersal.

In conclusion, second-instar jack pine budworm establish more readily in pollen-cone buds than in vegetative buds and are more likely to disperse from shoots bearing vegetative buds. Dispersal is the key factor that contributes to the mortality of second instars because budworm which fall to the ground have a negligible chance of climbing up into the canopy of the tree and finding suitable feeding sites. The alternate hypothesis is that pollen cones provide enhanced nutrition and thereby increase survival. However, Lejeune (1950) found no ultimate difference in the head capsule size and growth rates of budworm reared on pollen cones and vegetative shoots. The establishment and dispersal behaviour that has been observed here for individual budworm explains both the aggregation of budworm in pollen cones of the host tree and the increased dispersal of newly-emerged budworm from trees with few pollen cones (Batzer and Jennings 1980; Nealis and Lomic 1994). The results of this experiment and previous work (Graham 1935; Hodson

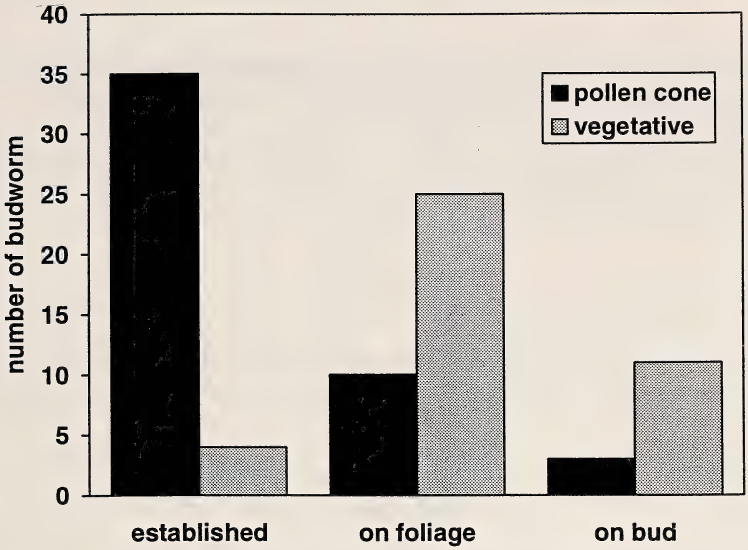

FIGURE 1. Location of the budworm after 30 minutes. The graph indicates the number of budworm that established in the bud, were found on the year-old foliage or on the bud for vegetative and pollen-cone shoots.

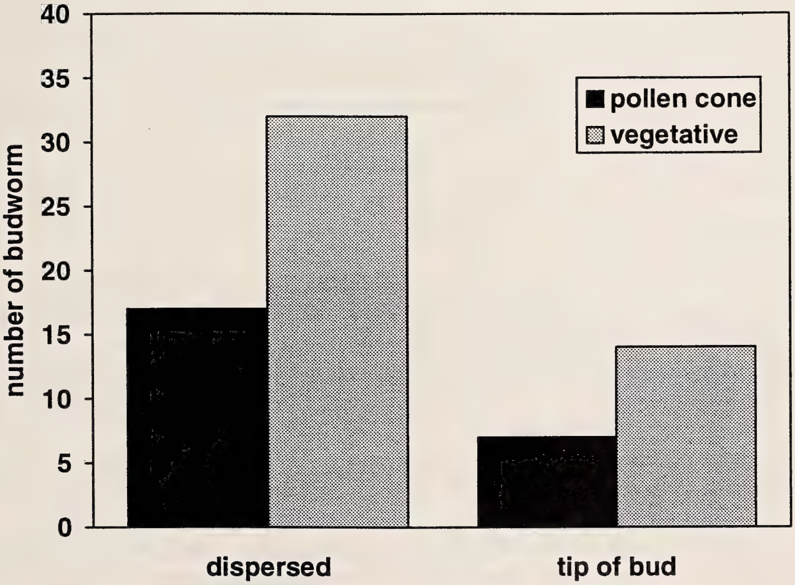

FIGURE 2. Behaviour of the budworm during the experiment. The graph indicates the number of budworm that dispersed from the shoot or were observed at the tip of the bud for vegetative and pollen-cone shoots.

and Zehngraff 1946; Lejeune and Black 1950; Foltz *et al.* 1972; Batzer and Jennings 1980; Clancy *et al.* 1980; Nealis and Lomic 1994; Lomic and Nealis 1995) suggest that evaluation of pollen cone abundance in stands should be incorporated into predictive tools for the management of jack pine budworm populations as pollen cones influence not only the spatial distribution but also the mean abundance of feeding budworm.

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TECHNIQUES FOR OBTAINING SCANNING ELECTRON MICROGRAPHS OF MINUTE ARTHROPODS

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Abstract *Proc. ent. Soc. Ont.* 127: 67–87

Techniques are described for preparing minute (0.1–5 mm) arthropods for obtaining high quality, low magnification (<5,000X), scanning electron micrographs. Included are scanning electron microscopy (SEM) procedures and the preparation of black and white prints. Techniques are also described enabling a single specimen to be remounted several times and viewed from different angles. Ultra fine hand tools are fabricated from tungsten wire and electrolytically sharpened. Organic debris is removed from specimens after critical point drying, by soaking in H_2O_2 and then rinsing in 100% ethanol. Specimens are gold coated on the underside first, then mounted on SEM stubs with the gold-coated side down, and gold coated again. This provides better conductivity between specimens and SEM stubs, permitting the use of higher SEM accelerating voltage (kV) settings with virtually no charging, and resulting in improved resolution of micrographs. Thicker gold coats on the underside of specimens, higher kV's, increased contrast settings of the SEM, and positioning of the SEM's stage to a horizontal plane are essential in producing the desired black backgrounds. The use of carbon conductive or Scotch No. 666 double-sided tapes is essential for attaching specimens directly to SEM stubs and for maintaining smooth uniform backgrounds.

Résumé *Proc. Soc. ent. Ont.* 127: 67–87

On décrit des techniques de préparation pour les arthropodes de très petite taille (0.1–5 mm) grâce auxquelles on obtient des images de grande qualité à faible grossissement (<5,000X) au microscope électronique à balayage. On y ajoute entre autres des méthodes de microscopie électronique à balayage (MEB) ainsi que la production d'images en noir et blanc. On présente également des techniques permettant de monter un même spécimen plusieurs fois pour l'examiner sous différents angles. On explique la fabrication d'ultra-outils manuels avec un filament de tungstène et l'aiguisage électrolytique. Après le séchage au point critique, on élimine les débris organiques en faisant tremper le spécimen dans H_2O_2, puis on le rince à l'éthanol à 100%. On le métallise ensuite avec de l'or qu'on vaporise d'abord sur la face ventrale puis, après l'avoir monté sur le porte-échantillon en plaçant la face métallisée vers le bas, sur la face dorsale. La conductivité entre le spécimen et le porte-échantillon étant meilleure dans ces conditions, on peut utiliser une tension d'accélération (kV) plus élevée, avec une charge virtuellement nulle, et obtenir ainsi une meilleure résolution des micrographes. Pour obtenir un fond noir, il est essentiel que la couche d'or soit plus épaisse sur la face ventrale du spécimen, que la tension d'accélération et le contraste soient plus élevés et que le porte-objet soit horizontal. Il importe également d'utiliser un ruban adhésif deux faces conducteur en carbone ou Scotch No. 666 pour coller le spécimen directement sur le porte-échantillon et obtenir un fond uniformément lisse.

Introduction

The use of scanning electron microscopes (SEM) permits detailed study and illustration of small arthropods (e.g., Eisenbeis and Wichard 1987) or their morphological structures, both external (e.g., Heraty and Darling 1984) and internal (e.g., Gibson 1985; Heraty 1989). Micrographs are often an ideal supplement to taxonomic descriptions, permitting a species or structure to be illustrated with an accuracy not possible by other means. Optical microscopes magnify no more than 2,000X and resolve objects no better than about 2,000 Å whereas some electron microscopes can magnify to 20,000,000X with a resolution on the order of 2 Å (Weaver 1977) (for non biological material). Obtaining high quality micrographs, especially at low magnification (<2,000X), for morphological study and publication can be difficult. Even though many authors routinely use micrographs in their publications, they usually give only a minimum of information on techniques for specimen preparation and production of high quality micrographs. While this is not surprising - the purpose of their research is to present results, not technical details of methods used - it would be useful to have a single publication treating techniques from specimen preparation to final micrograph production. Few publications provide more than minimal information on such techniques (e.g., Eisenbeis and Wichard 1987; De La Cruz and Estrada-Peña 1992; Corwin *et al.* 1979). The purpose of this paper is to describe in detail methods for preparing small arthropods for scanning electron microscopy and production of high quality micrographs. Fabrication of ultrafine hand tools, specimen preparation, SEM stub mounting methods, gold coating recommendations, scanning electron microscope procedures, darkroom techniques, and micrograph preparations are discussed. This information should permit researchers to produce high quality SEM micrographs with a minimum of time and effort.

Scales of measurement are illustrated as lines on all figures except Figure 6 and represent 0.1 mm unless otherwise indicated.

Materials and Methods

Production of consistently high quality SEM micrographs cannot be attributed to any one particular procedure. Care must be taken during all aspects of specimen and micrograph preparation. An individual's technical skill may influence the quality of work; however, the following procedures should help improve the results. Unless otherwise indicated, adults of Mymaridae (Insecta: Hymenoptera), commonly known as fairy flies, are used to illustrate techniques. Members of this family, all of which are parasitic on the eggs of other insects, are challenging subjects for SEM work because of their small size (0.2-4.5 mm long, Noyes and Valentine 1989) and, in many species, their soft bodies. The techniques described here can be successfully applied to other small arthropods, for example, mites and apterygote insects. Stubs used for mounting specimens are 12 mm in diameter. Slightly larger specimens (or pieces of specimens) can be mounted on these stubs and viewed with the SEM; however, a maximum of approximately 4.5 mm of the subject can be viewed at one time when scanned at the lowest magnification of approximately 10X.

Specimen fixation

All specimens were fixed in 70% ethanol for a minimum of 12 hours (Eisenbeis and Wichard 1987). Specimens can also be pre-fixed in isotonic osmium tetroxide followed by glutaraldehyde as the main fixative, however using 70% ethanol was a simpler technique and produced excellent results. Cleaning specimens at this stage, with the use of detergents such as Alconox® (Keirans *et al.* 1976) or Terg-A-Zyme®, dissolved in water, would necessitate their rehydration and their subsequent dehydration. This increases the possibility of mechanical damage through extra handling and increases the prospect of tissue distortion through osmosis. Therefore alternate cleaning procedures were usually performed *after* the specimens had undergone critical point drying (CPD).

Specimen dehydration

Small (12 mm diameter X 14 mm high) microporous specimen capsules (available from Cedarlane Laboratories Ltd., Hornby, ON) were immersed right side up, in a shallow dish containing 95% ethanol. The specimens were loosely placed inside the capsules and the lids secured. Specimens were transferred to the capsules with as little liquid as possible to avoid contamination from possible dirt suspended in the containment liquid. The specimens should not be transferred by means of an eye dropper, but rather individually transferred with a hooped micro-probe. The capsules were left to soak for 8 hours, removed from the liquid to allow excess ethanol to drain out through the pores onto paper toweling, and immediately placed in 100% ethanol for 8 hours and again in fresh 100% ethanol for another 2 hours. Placing specimens in capsules, at the beginning of the dehydration steps, reduces the possibility of damaging or losing them through handling.

Specimens fixed in 70% ethanol for longer than 12 hours should, if possible, be rapidly dehydrated to prevent excessive shrinkage. This can be accomplished by warming the alcohol to 30°–40°C to ensure faster penetration (Eisenbeis and Wichard 1987).

Specimen drying

The capsules were drained and placed in a sock made from nylon (the foot of a nylon stocking works well), the opening was closed off with a twist tie, and the sock was promptly placed into a Bio-Rad E3100 Jumbo Series II® CPD apparatus for critical point drying of specimens, using liquid carbon dioxide (CO_2) (Gordh and Hall 1979). The CPD apparatus can hold 50 capsules at one time, and these collectively can accommodate numerous specimens (e.g., up to 4,000 3 mm long Hymenoptera: Chalcididae) in one run. Purging was continued until all signs of ethanol were eliminated. Specimens were left to soak undisturbed in the liquid CO_2 for 15 minutes and then purged for 20 seconds, for about 5 or more cycles, until the purged CO_2 appeared as dry snow and would not stick to the inside walls of the purging tube. To observe the condition of the purged CO_2, the use of clear tubing such as Tygon® attached to the purge nozzle is necessary. Most of the ethanol purged comes from ethanol accumulated in the capsules. However, larger specimens require longer soaks and more purges to replace the impregnated ethanol with liquid CO_2.

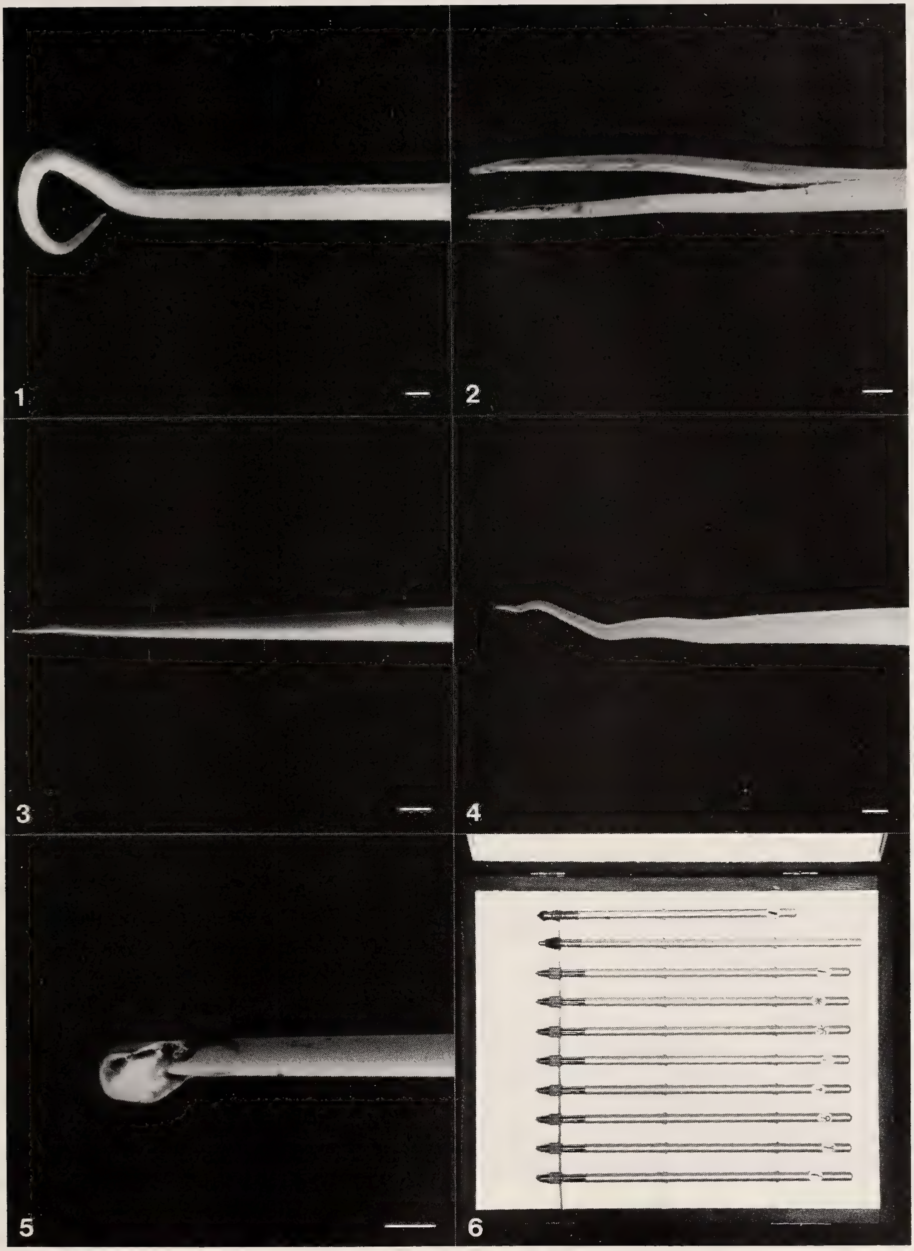
The microporous specimen capsules should be cleaned occasionally by soaking in undiluted Javex® bleach for 15 minutes and rinsing several times in distilled water, preferably with an ultrasonic cleaner. This eliminates the possibility of contaminating the specimens with foreign particles left in capsules from previous CPD runs.

Critical point drying renders the appendages of specimens more flexible than air drying of specimens, so that limbs can be better positioned to create lifelike poses.

Hand tools and hand tool preparation

Precision hand tools are essential for handling, dissecting, and cleaning specimens. Fine forceps with tips measuring 0.10 X 0.06 mm or smaller are necessary (e.g., No. 5 forceps made by a number of companies including A. Dumont et Fils of Switzerland). Fine No.3/0 artists' brushes are used for handling larger dry or wet specimens, and pipettes or eye droppers for moving many specimens at a time from one liquid to another. However, eye droppers should not be used for transferring specimens to microporous specimen capsules. Other hand tools were custom fabricated from 15 mm lengths of 10 mil (0.25 mm) tungsten wire sharpened through electrolysis in 10% potassium hydroxide (KOH) (Norton and Sanders 1985) and held in zero-closure pinholders. This method is essential for producing ultrafine microprobes not otherwise available from scientific suppliers. Using longer pinholders with shafts approximately 17 cm long enables better control in manipulating specimens at high magnification. Six different styles of microprobes were custom made and are recommended for handling and cleaning specimens: hooped, two-pronged, tapered, sticky, hair, and paper point (Figs. 1–5). Recommended probes:

- Hooped microprobes (Fig. 1) were made in two sizes, with hoops 0.1 and 0.5 mm in diameter, from long tapered points shaped with tweezers under a stereomicroscope. These probes are used for scooping up whole or dissected specimens from liquids, thus eliminating the need for forceps which can damage the specimens. The hoops eliminate excess liquid, a possible source of dirt or chemical contamination held by capillary action between the tines of the forceps.
- Two-pronged microprobes (Fig. 2) were made by immersing 4 mm of the tips of unsharpened tungsten wires into the KOH electrolyte at right angles to the surface for approximately 20 seconds with the transformer set at 8V. The resulting rapid electrolytic reaction initially fractures the tips lengthwise, creating double-pointed prongs approximately 1 mm long. If left in the electrolytes longer, the double prongs continue to erode into a single sharpened point. Progress was checked under a stereomicroscope until the desired prongs were attained. Two-pronged microprobes are useful tools for dissecting specimens, e.g., separating the heads of insects from the rest of the body.
- Tapered microprobes were made with very fine elongated tapers (Fig. 3) or medium tapers with slight crooks (Fig. 4). The crooks were fashioned with forceps under a stereomicroscope. Probes with fine elongated tapers are used for delicate manipulations at higher magnifications. Probes with a medium taper and slight crook are used for coarser manipulations and lifting and moving small pieces (e.g., antennae, legs).
- Sticky microprobes were made from straight, medium tapered probes with dabs of sticky-tape glue removed from 3M Scotch brand two-sided sticky-tape No.666 on their tips (Fig. 5). One probe may have a dab approximately 0.2 mm in diameter and another a dab approximately 0.05 mm in diameter. Sticky microprobes are useful for lifting and moving whole specimens or body parts or removing pieces of visible dirt from specimens already mounted on SEM stubs. The dabs of glue must be replaced periodically as they become contaminated with dirt particles. Sticky microprobes were also made from tapered probes coated with a weak solution of adhesive made by dissolving 2.5 cm^2 pieces of Scotch No. 666 two-sided tape in 3.5 ml ethyl acetate. The resulting film on the probes remains slightly tacky when dry. These probes are useful for safely lifting and moving very delicate, dry samples (e.g., antennae) from one area to another.



FIGURES 1–6. (**1**) Hooped microprobe, with hoop 0.5 mm in diameter. (**2**) Two-pronged microprobe. (**3**) Microprobe with fine elongated taper. (**4**) Microprobe with medium taper and a slight crook. (**5**) Microprobe with dab of sticky-tape glue on tip. (**6**) Container for holding microprobes, made from stiff paper, notched and folded into shape, and glued into a box previously used to house microscope slides.

- Eyelash or hair probes were made by gluing an eyelash or hair on the end of a piece of blunt tungsten wire. These probes are useful for removing loose, unwanted particles of dirt from delicate areas such as membranous tissues or between setae. The eyelash or hair is usually charged with static electricity which will normally dislodge the specks of dirt; if not, the specks might be safely flicked off.
- Paper point probes were made from tiny, tightly rolled papers (also available through Pelco International), and held in pin holders. They can be aimed accurately at drops or wet areas to absorb excess liquid from specimens after their removal from alcohol rinses. This process helps to prevent possible contamination from particles of dirt which may be suspended in the liquids.

The microprobes were all stored flat and kept separate and immobile on a tray specifically constructed to protect their points but allowing easy access (Fig. 6). Since the various microprobe tips are difficult to distinguish with the naked eye, their stems were individually marked with descriptive illustrations for easy recognition. The tips of the tools would inevitably get dirty and were cleaned by lightly touching the surface with sticky-tape as needed.

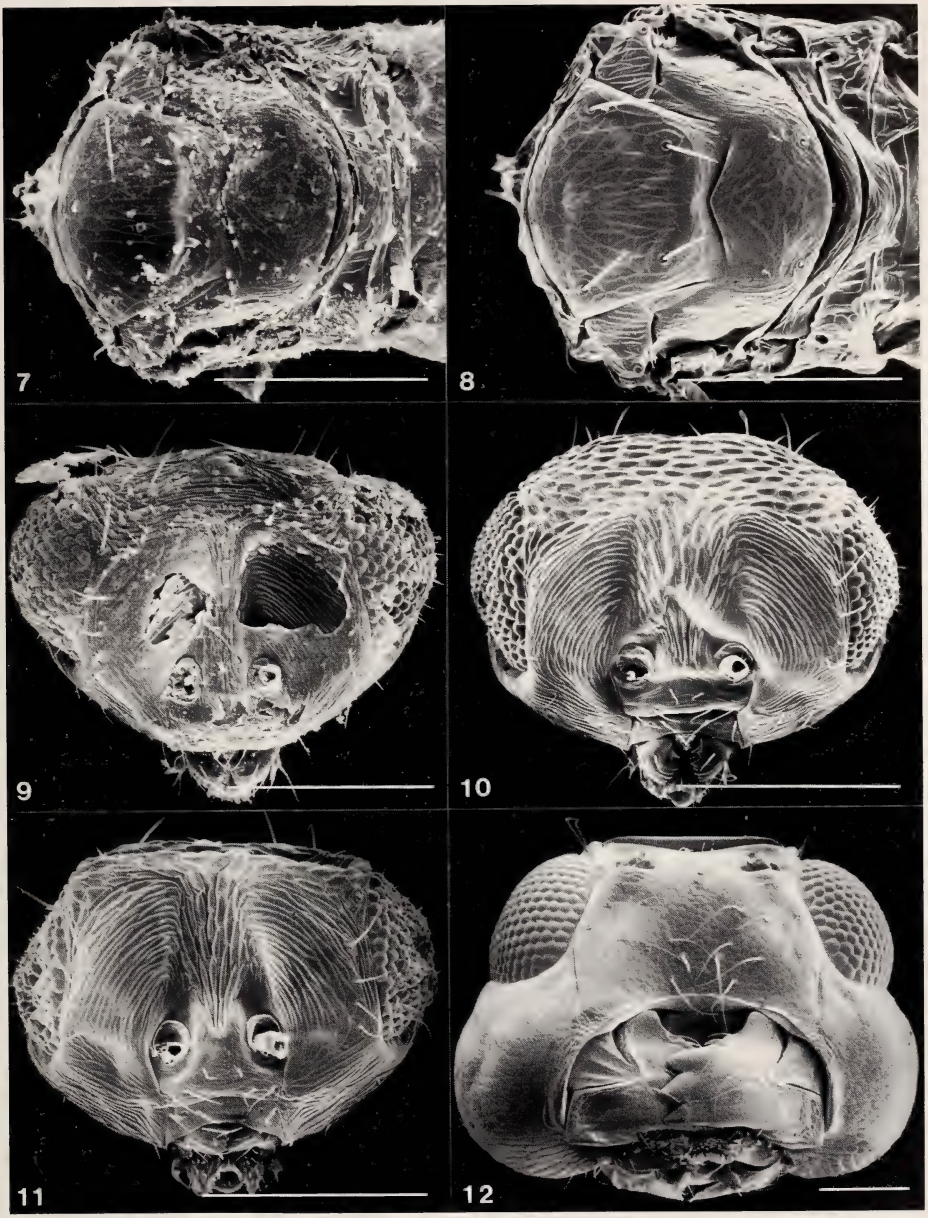
Cleaning

All specimens were cleaned before being mounted on SEM stubs even if they appeared clean at high magnification under a stereomicroscope. There is usually an organic film or other foreign particles adhering to the exoskeleton which can only be detected when viewed with the SEM (Figs. 7 and 9). High quality micrographs revealing unobstructed morphological details can best be obtained from cleaned specimens (Figs. 8 and 10), though computer technology can be used to "clean" digitized micrographs.

Ultrasonic cleaning, using appropriate cleansers (Keirans *et al.* 1976; De La Cruz and Estrada-Peña 1992), is an excellent method for cleaning arthropods with robust exoskeletons (e.g., many adult insecta and mites). However, it is not recommended for cleaning delicate specimens such as adult Mymaridae as they disintegrate during this procedure.

All specimens were cleaned in the same manner, whether previously air dried or subjected to critical point drying. Before the specimens were cleaned, their wings, if present, were removed and stored separately in vials with appropriate labels, usually for slide mounting at a later time. Wing removal was accomplished by gently holding the specimen at the bottom of a glass cavity slide (75 X 27 X 7 mm with round, centrally located, flat bottomed cavities 15 X 4 mm) with a pair of fine forceps, and grasping and delicately twisting the base of each wing with another pair of fine forceps. It is important to use glassware rather than plastic ware for dissection or containment dishes in order to minimize the unwanted adhesive effects of static electricity.

Debris or film found on specimens was usually organic; however, if the debris was inorganic it was stuck to the specimens with organic compounds such as substances extruded from the specimens. The preferred solution used for cleaning was 50% stabilized hydrogen peroxide (H_2O_2) which gently dissolved most of these organic compounds through oxidation, without disfiguring the specimens. Specimens were soaked in this solution for 5–20 minutes, depending on the extent of sclerotization. Delicate specimens of Mymaridae or Trichogrammatidae (Hymenoptera) (Fig. 11) suffered some tissue distortion, such as deformed abdomen, eyes, head, and antennal segments, when held in H_2O_2 for longer than 5 minutes. However, little or no distortion was observed (Fig. 10) when they were soaked for up to 5 minutes. More robust specimens (e.g., *Australomymar* sp. Fig. 12, and *Erdosiella* sp. Fig. 15) suffered no tissue distortion when held in H_2O_2 for 20 minutes or even longer. A 20 minute soak was usually more than adequate to dissolve most unwanted organic films. Thin or elongate membranous tissues such as wings or the parempodia on the apical



FIGURES 7–12. **(7)** Trichogrammatidae, *Trichogramma minutum* Riley ♀, thorax, dorsal view, not cleaned. **(8)** *T. minutum* ♀, thorax, dorsal view, cleaned in H_2O_2 for 5 minutes. **(9)** *T. minutum* ♀, head, dorsal view, not cleaned. **(10)** *T. minutum* ♀, head, dorsal view, cleaned in H_2O_2 for 5 minutes. **(11)** *T. minutum* ♀, head, dorsal view, cleaned in H_2O_2 for 20 minutes. **(12)** Mymaridae, *Australomymar* sp. ♂, head, ventral view, cleaned in H_2O_2 for 20 minutes.

tarsomere of Heteroptera (Fig. 14) curl if left in H_2O_2 for even less than 3 minutes (Fig. 13).

To break surface tension, suitably sized hooped microprobes were used to submerge the specimens. Once held there for a few seconds, the specimens would usually remain submerged unassisted for the required time. However, if they continued to float to the surface, they could be resubmerged and attached to a bubble, formed on the bottom or sides of the containers, or they could be gently pushed under small pieces of fine wire screens, or other similar heavy objects, placed in the containers. Bubbles can form on the specimens as a result of the organic compounds being oxidized. Therefore, it was necessary occasionally to lift the specimens out of the solution and resubmerge them to eliminate the bubbles and ensure uniform contact with the cleaning solution. The H_2O_2 gradually loses its effectiveness when exposed to air, making it necessary to use fresh solutions on a daily basis.

Soaking specimens in a mixture of 70% ethanol and 50% hydrogen peroxide at a 50:50 ratio immediately after fixation for approximately 30 minutes will remove lighter debris or film. This process eliminates the need for cleaning specimens after they are subjected to CPD. The ethanol/hydrogen peroxide solution can also be used effectively to float arthropods away from heavier debris found in Berlese trap (or similar) samples.

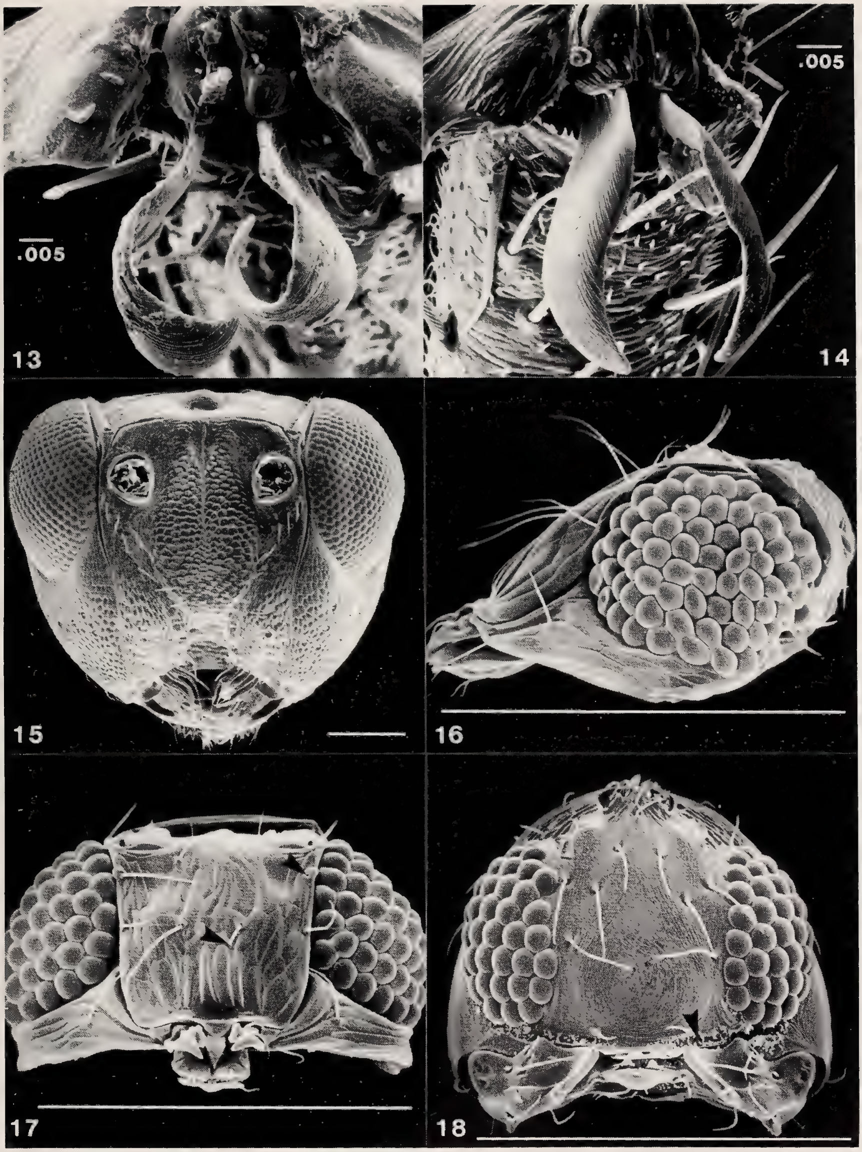
Javex® bleach, with a concentration of 5.25% sodium hypochlorite (NaOCl), also dissolves undesirable deposits of organic debris. It damages the specimens more quickly than H_2O_2, demanding shorter cleaning times. However, bleach will not produce bubbles on the specimens. The reaction can thus be monitored under a stereomicroscope, enabling the timely removal of the specimens before their exoskeletons become affected.

An 85% solution of lactic acid ($C_3H_6O_3$) can also be used to remove unwanted debris but requires longer cleaning times. Specimens of Mymaridae have been left to soak for 4 days without affecting the exoskeleton.

Proper safety precautions must be taken when handling H_2O_2, $C_3H_6O_3$, and NaOCl due to their highly corrosive properties, especially when used at the concentrations recommended here for cleaning specimens.

Cleaned specimens were rinsed in two changes of 100% ethanol, in small, capped vials which were gently agitated by hand for a minimum of 2 minutes each time. They were then removed with hooped microprobes and placed to dry on round (8 mm diameter), white paper tabs affixed to glass slides. The tabs act as miniature blotters to absorb the excess ethanol. If liquid remains on the specimens, then paper point probes are immediately used to soak up the excess. It is important to prevent excess ethanol from evaporating on the specimens to avoid possible recontamination by minute dirt particles which might be suspended in the liquids. Glass depression slides and cover slips are ideal for temporarily storing and protecting newly cleaned specimens.

An alternative method for cleaning the detached heads or thoraxes is with the use of Scotch No. 666 sticky-tape. Appropriately sized pieces of tape are affixed to SEM stubs. The heads with antennae removed or thoraxes with legs removed are placed on the tape and carefully rolled around until all sides have made contact with the tape's adhesive surface. Hazy tracts of dirt indicate the effectiveness of the cleaning procedure. The specimens are then rolled to clean areas of the tape and left for SEM viewing in the desired position. Abdomens are usually too delicate for this procedure. This technique was used successfully even on the tiny heads (0.12 mm width) of minute specimens such as *Dicopus* sp. (Figs. 16, 17), although occasionally setae would be lost or broken (Fig. 17) or dirt would be left in the deeper crevices as in *Palaeomymar* (Fig. 18). It is important to maintain the temperature of the sticky-tape at 20°C or lower; otherwise the adhesive becomes overly tacky, making it difficult to roll the specimens without damaging them.



FIGURES 13–18. (**13**) Miridae, *Salignus tahoensis* (Knight), (Heteroptera), apical tarsomere, semi-anterior view of parempodia which curled after having been soaked in H_2O_2 for 2 minutes. (**14**) *S. tahoensis* apical tarsomere, semi-anterior view of normal, untreated parempodia. (**15**) Mymaridae, *Erdosiella* sp. ♂, head, anterior view, cleaned in H_2O_2 for 20 minutes. (**16**) Mymaridae, *Dicopus* sp. ♀, head, lateral view, cleaned by rolling on Scotch No. 666 sticky-tape. (**17**) *Dicopus* sp. ♀, head, ventral view, cleaned by rolling on Scotch No. 666 sticky-tape; arrows indicate setae lost and broken during cleaning. (**18**) Mymarommatidae, *Palaeomymar* sp. ♀, head, ventral view, cleaned by rolling on Scotch No. 666 sticky-tape; arrow indicates dirt not removed in crevices.

A technique for cleaning that can be used on more robust specimens is to anchor them firmly with Leech's Multi-Purpose Glue and apply acetone-thinned glue (2 ml glue mixed with a few drops of acetone) over their surface. The glue is later peeled off when nearly dry, removing the undesirable deposits with it (Corwin *et al.* 1979). Alternatively, rubber cement can also be used in the same manner as described above (McGinley 1986). These techniques should not be used on delicate membranous tissue or on areas where the removal of setae is not desired. This procedure is useful when the removal of all setae is necessary to expose the surface structures of the exoskeletons (e.g., some Hymenoptera: Apoidea).

First gold coat

Specimens should be gold coated at least twice. The first coat is applied before the specimens are dissected and the final coat after they are dissected and positioned on SEM stubs.

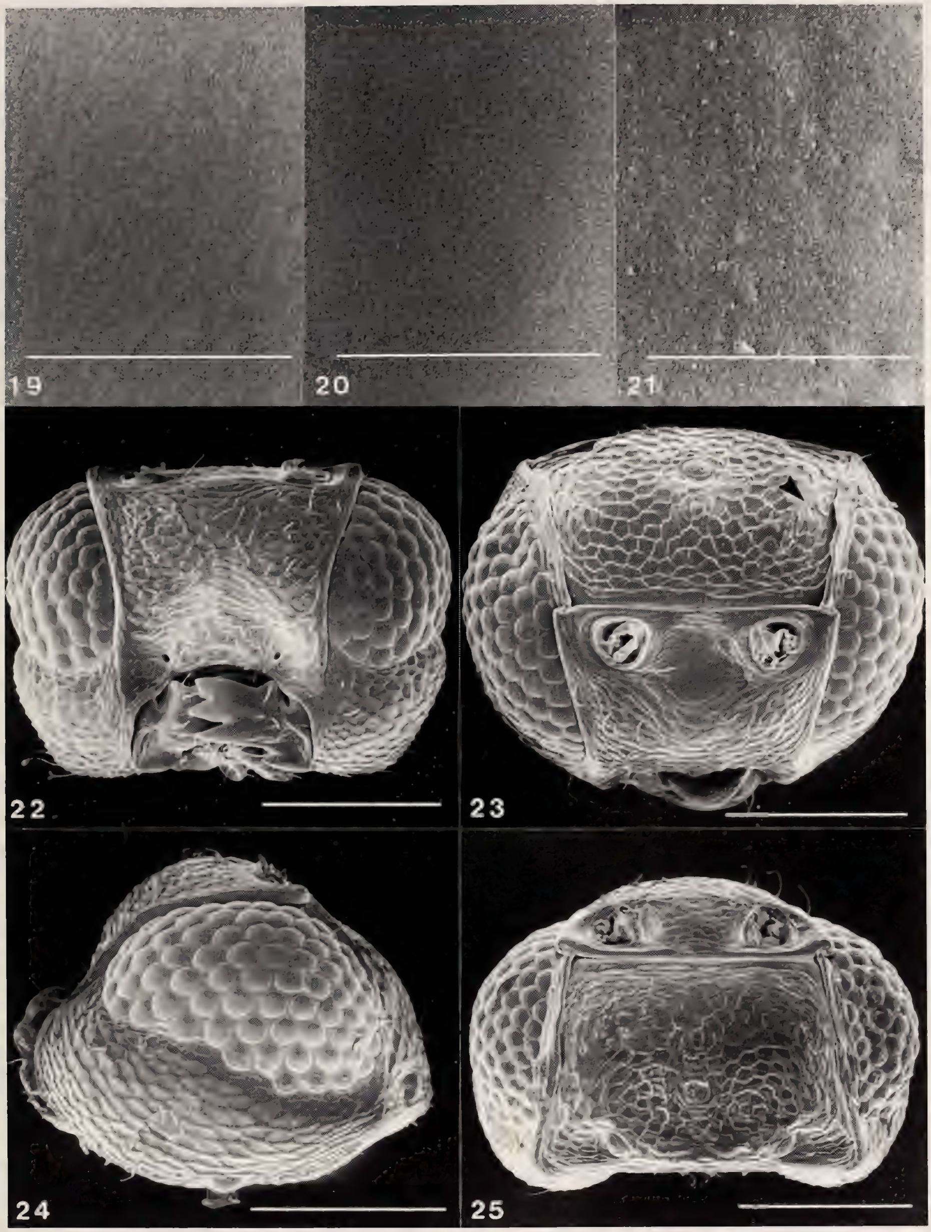
A weak solution of glue made by dissolving 2.5 cm^2 Scotch No. 666 sticky-tape in 3.5 ml ethyl acetate was used to affix small pieces (3 cm^2) of plastic insect screening (with 1.5 mm^2 mesh) to the bottoms of small glass petri dishes (7 cm diameter). Plastic petri dishes are not recommended for this procedure because ethyl acetate will dissolve them. The glue remains slightly tacky when dry, allowing smaller specimens (<1.6 mm long) to be safely attached within the individual squares. Specimens suffer no damage when removed from this adhesive. The squares can be enlarged, by cutting with a sharp pointed blade under a stereomicroscope, to accommodate larger specimens. However, as this adhesive is very weak it is recommended that larger specimens (>1.5 mm long) be attached to small dabs of adhesive removed from Scotch No. 666 sticky-tape by their thorax or their legs. Attaching larger specimens to dabs of Scotch No. 666 sticky-tape adhesive by their legs should be done only if the legs are expendable, as the legs are difficult to detach intact from the adhesive. The specimens were affixed with the side desired for final viewing face down, thus exposing the opposite sides of the specimens to the first gold coating. A petri dish with insect screening can accommodate many specimens at a time for each gold coating operation.

A Technics Hummer® gold sputter coater was used for gold coating the specimens. High voltage was set at 10 kV and the vacuum was adjusted between 50 and 55 millitorr to achieve 10 mA sputters. Sputtering was timed for 5 minutes resulting in coatings of approximately 400 Å thick. The specimens were then removed and dissected.

Dissecting and mounting on SEM stubs

To enhance the image in SEM micrographs, smooth, clean, and uniformly black backgrounds are preferred. Carbon conductive tabs (Fig. 19), manufactured by Ted Pella Inc. in a 12 mm OD format, and Scotch No. 666 sticky-tape (Fig. 20), have adhesives on both sides. These tapes have exceptionally smooth surfaces even when viewed at 500X magnification. The adhesive on the carbon tabs is softer than the Scotch No. 666 sticky-tape, but proved to be a better electrical conductor. Scotch copper conducting tape, carbon tape manufactured by Shinto Chemical Co. and JBS sticky tabs were also tried but proved to have a rougher texture. Conductive silver sticky tabs and sheets are also available but were not sampled for this study. Most of the micrographs taken for this paper were taken from specimens mounted on carbon tabs. Sticky tapes have the added advantage of not obscuring the parts of the specimen that make contact with the glue, as the specimen when properly mounted will sit securely on the glue surface. Silver glue or silver paste are good conductors but make poor adhesives for delicate samples, as their surfaces dry rapidly, making it difficult to attach specimens or, if the glue is too runny, soaking onto the specimen.

Metallic colored fingernail polish (Fig. 21) can be used as an alternative adhesive for mounting specimens on SEM stubs (Bryant *et al.* 1991). It provides a good conductive surface but



FIGURES 19–25. (**19**) Carbon conductive sticky-tab, surface features at 500X. (**20**) Scotch No. 666 sticky-tape, surface features at 500X. (**21**) Colored fingernail polish, surface features at 500X. (**22**) Mymaridae, *Caraphractus cinctus* Walker ♀, head, ventral view, first mounting. (**23**) *C. cinctus* ♀, head, anterior view, first remounting of same specimen as in Figure 21; arrow indicates residual glue from sticky-tape. (**24**) *C. cinctus* ♀, head, lateral view, second remounting of same specimen as in Figure 21. (**25**) *C. cinctus* ♀, head, dorsal view, third remounting of same specimen as in Figure 21.

has a less uniform background and it is not possible to remove specimens for repositioning without damaging them.

Appropriate sized pieces of sticky-tape were affixed to cleaned SEM stubs and the dissected body parts were gently laid (never pressed down) in their final viewing position, with the gold coated side face down on the tape. The pieces of tape must always be large enough to fill the viewing frame of the SEM screen to ensure a uniform background.

Glass cavity slides were used for dissecting the specimens. Overexposed and developed RC photographic paper was cut to size and glued to the bottom of the cavities to provide black backgrounds for easier specimen examination. The photographic paper provides a lint free environment and cushion for anchoring the forceps points, while holding specimens in place against the bottom. The slides were placed in shallow glass petri dishes (10 cm diameter or larger) and together placed on the stereomicroscope stage which had previously been lined with clean white paper. These precautions improve the chances of finding specimens if they are accidentally blown or flicked out of the cavity slides. The specimens were dissected in the cavity slide with appropriate microprobes and forceps.

Containment and dissecting dishes should be small to make it easier to locate specimens. It is good practice to dust dissecting dishes and tools with compressed air before use. Compressed air in cans, such as Fisherbrands' Phfft®, is a convenient source. Lint-free tissue such as Kimwipes®, made by Kimberly-Clark, should be used for wiping dishes or utensils. The immediate areas around the microscopes must be kept dust free, and fans that might create even the lightest air turbulence must be turned off. Cardboard barriers are helpful in deflecting air currents created by the cooling fans of some microscope light transformers. Breathing must also be controlled at critical moments to prevent air movement. Portable humidifiers are useful in areas of low humidity. Higher humidity helps reduce excessive static electricity buildup on dissecting tools and dishes, allowing for easier and safer manipulation of specimens.

The following description is an example of parts dissected, mounted, and photographed for a comprehensive study of external features of Mymaridae.

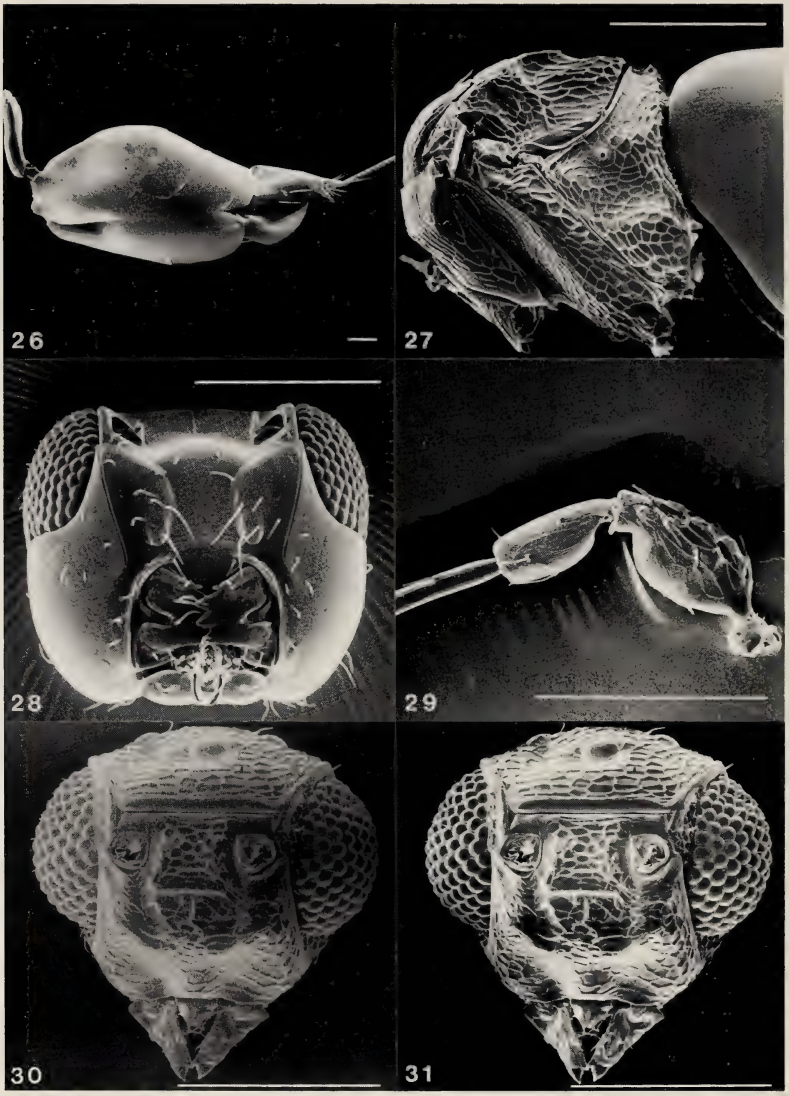
- Antennae were removed first and mounted lengthwise on SEM stubs with one antenna positioned to view the inner lateral aspect and the other positioned to show the outer lateral aspect. Whole specimens were delicately held at the bottom of the cavity slide with forceps and the antennae gently moved back and forth at their base, with the crooked microprobes, until they became detached. Using forceps to grasp the antennae during removal will usually crush or break them.
- Heads were detached by applying light pressure between the head and thorax with the two-pronged microprobe or by gently pushing back and forth with a stout, single-pointed microprobe. Usually five views of the head were photographed: dorsal, ventral, lateral, posterior, and anterior. If enough specimens of the same species were available, then five different heads were mounted, one for each aspect. However, if few specimens are available, a single head can be removed from the sticky-tape after SEM examination and remounted on fresh tape a number of times (Figs. 22–25). The head is remounted by gently rolling it over onto the surrounding gold coated, non-sticky surface to detach it from where it was stuck to the sticky-tape. It is then picked up with a sticky microprobe (with the light coating of glue) and remounted. Each time it is remounted it must be coated with gold again, as described later under 'Second Gold Coat'. Occasionally setae are lost or some remnants of glue are left on the specimen, especially if the softer carbon conductive tabs are used (Fig. 23). Specimens are always mounted with the desired aspect facing straight up and parallel to the surface of the stubs.

- Thoraxes were detached from the abdomens if they were connected by petioles, the petioles remaining attached to the abdomens (Fig. 26). A specimen was delicately held at the bottom of the cavity slide with forceps while the abdomen was gently moved back and forth with microprobes until it became separated. If the petiole was short, then the forked microprobe was useful to help pry the abdomen apart from the thorax. When the thorax and abdomen were broadly attached (without a petiole) they were mounted, undivided, on the SEM stubs (Fig. 27). Usually four views of the thorax were photographed: dorsal, lateral, ventral and anterior. For dorsal, lateral, and anterior views the legs were removed below the coxae and could be saved with the wings or, if needed, mounted on SEM stubs. For ventral views, the legs were removed above the coxae, which then gave an unobstructed view of the thorax. Occasionally coxae will not detach easily with the rest of the legs but remain attached to the thorax. In this case it is best first to mount the thorax on the stub, where it can be held in position by the sticky-tape. Microprobes are used to gently loosen the coxae which can then be removed with sticky microprobes. Care must be taken to prevent the coxae from accidentally falling on the tape near the specimen to ensure they will not unintentionally appear in the background of the micrographs; removing them will blemish the tape surface. Enlarged dorsal views of the propodeum and dorsellum were also photographed. If few specimens were available, the thorax could also be remounted several times to obtain micrographs of different aspects.
- Abdomens are always more fragile than the head and thorax and demanded extra care when handled. Three views were usually photographed: dorsal, lateral, and ventral. The male's abdomen was also photographed from the posterior to show cerci, and genitalia if extruded. Abdomens are difficult to remount intact, due to their delicate nature, although with more robust individuals of genera such as *Bruchomymar*, this can be successfully accomplished. If remounting is not possible, then it is necessary to mount several different specimens in various positions. If needed, single specimens can be photographed at two of the desired aspects by mounting them laterally on the stub at a 45° angle and then tilting the SEM stage. However, photographing specimens on a tilted stage should be avoided, for reasons discussed later under 'Scanning Electron Microscope Procedures'. Enlarged dorsal and lateral views of the cercal plates and setae were photographed, as well as enlarged dorsal, lateral, and ventral views of the petiole, when present. Micrographs of enlarged dorsal, lateral, ventral, and posterior views of male genitalia were also taken. Mounting abdomens vertically, with their anterior ends attached to the stubs and tilting the stage to 90°, will facilitate viewing the genitalia of one specimen from all angles.

In order to prevent airborne particles from contaminating specimens mounted on stubs, the specimens should always be kept in storage containers or under inverted glassware (beakers for example) when not being worked on.

Second gold coat

Before the specimens are gold coated again they must be checked under a stereomicroscope at high magnification for any visible specks of dirt. These usually originate from airborne particles which settle on the specimen during dissecting or mounting. Particles are removed with sticky microprobes or eyelash probes. If a dirty specimen is gold coated, the dirt cannot be removed afterwards without leaving permanent marks. The procedure for the second gold coating of specimens on sticky-tape is more problematic than when the first gold coat is applied, because heat produced during the sputter can create wrinkles (Fig. 28) or even cracks (Fig. 29) on the tape surface. These distortions always radiate out from, or are parallel to, the specimens, and reduce



FIGURES 26–31. Mymaridae. **(26)** *Bruchomymar* sp. ♀, abdomen, lateral view, with petiole attached. **(27)** *Litus cynipseus* Haliday ♀, thorax and abdomen, lateral view, broadly attached, with no petiole. **(28)** *Polynema* sp. ♀, head, ventral view, with background showing wrinkles on carbon tab sticky-tape caused by excessive heat during gold sputtering. **(29)** *Stephanodes* sp. ♀, antenna, lateral view, with background showing cracks in Scotch No. 666 sticky-tape caused by excessive heat during gold sputtering. **(30)** *Anagroidea* sp. ♂, head, anterior view, photographed with SEM's settings for contrast and brightness on automatic and with stage horizontal. **(31)** *Anagroidea* sp. ♂, head, anterior view of same head as in Figure 29, photographed with SEM's settings for contrast and brightness manually set and with stage horizontal.

the quality of the background in the micrographs. To help reduce heat buildup a number of techniques could be used: using a water cooled stage in the gold coater; sputtering gold for less time and at a lower mA (2 minutes at 8–9 mA) which results in a coating approximately 140 Å thick; or using a pulse sputtering technique that produces an automatic sputter for 15 seconds every 15 seconds for 4 minutes.

A specimen that is entirely coated with gold will provide excellent conductivity with the SEM stub. Gold coating with one or more coats from the top only does not provide the same high level of conductivity. Gold that is sputtered from above over the usually rounded sample gives good coverage to the upper surface but results in increasingly thinner coverage down the sides and toward the underside. There is usually no gold at the point where the specimen makes contact with the adhesive, leaving a non-conductive barrier. Because of this poor conductivity, lower kilovolt settings on the SEM are necessary to reduce charging, resulting in micrographs of poorer quality. In contrast, a completely coated specimen permits the use of a higher kilovoltage with virtually no charging. Also, the thinner gold coat on the tape surface (approximately 140 Å), and the thicker coat on the bottom of the specimen (approximately 400 Å), increases the brightness of the specimen in relation to its background when the stub is positioned and viewed in a horizontal plane. If the background is visible on the micrograph, recoating the specimen and sticky tape a second time should be avoided. Instead, the specimens should be remounted on a fresh piece of tape and lightly gold coated again. This will further darken the background and lighten the specimen.

Positioning stubs at a 45° angle during gold coating and coating on at least two sides can be an alternative of last resort if it is impractical to use other techniques.

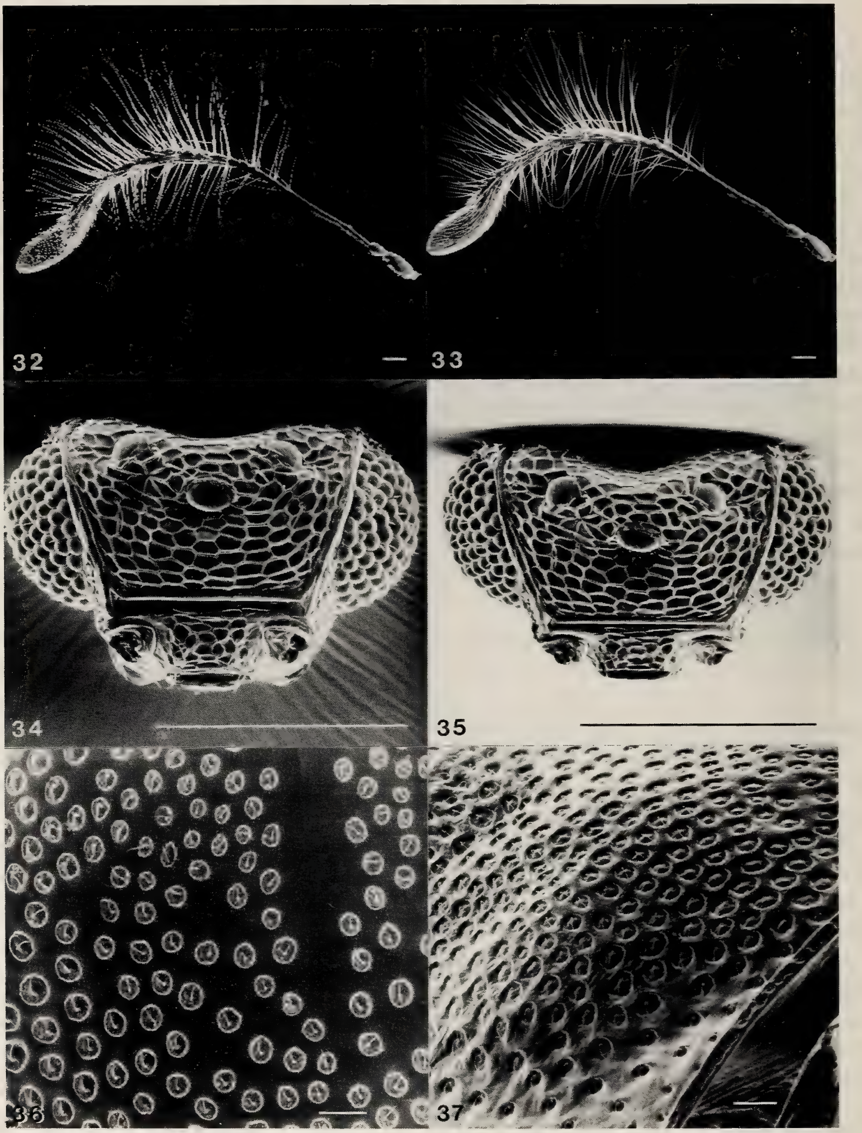
Scanning electron microscope procedures

A Cambridge S-100, an AMR 1000, and a Zeiss DSM 940A SEM were used in this study. Most of the micrographs illustrated here were taken with the Zeiss instrument and all the suggestions here apply to the Zeiss.

Before the specimens were viewed they were again examined for secondary contamination from airborne particles which might have landed on the gold coated surfaces. These dust particles can be removed with the sticky or eyelash probes taking care not to damage the gold coated surfaces. Dusting with compressed air is not recommended.

An aperture size of 80 μm and working distance of 15–30 mm were used. These settings produced a good balance between resolution and depth of field at the magnifications used (<5,000X). Accelerating voltage settings of 10–20 kV resulted in excellent resolution with virtually no charging effects, due to the conductivity of the specimens. The beam saturation of the filament was between 3.45 and 3.65 A, with a beam current of 50–80 μA. A medium spot size, which was set at 7, was used with a photo scan rate of 80 seconds. The photo settings were 45 for contrast and 20 for brightness. Secondary electrons were always used and the amplitude set at maximum; back scatter electrons were seldom used. Focus, contrast, and brightness settings were adjusted manually. The Zeiss SEM has the ability to perform these functions automatically but the automatic contrast and brightness settings result in flatter images and lighter backgrounds (Fig. 30). Adjusting contrast and brightness settings manually improves the image quality (Fig. 31). Manually adjusting the focus allows the freedom to focus on areas of interest.

The Zeiss has the capability to produce negatives from images stored in its computer memory (frame stored) or to store images on computer discs. However, these images are stored at 1024 X 1024 pixels with a resolution of 256 levels of grey (currently a limitation of the computer attached to the Zeiss) (Fig. 32) whereas analog (on-line) images are photographed at 2048 X 2048 pixels



FIGURES 32–37. (**32**) Mymaridae, *Bruchomymar* sp. ♀, antenna, lateral view, photographed through SEM's frame store feature, at 1024 X 1024 pixels and with a resolution of 256 levels of grey. (**33**) *Bruchomymar* sp. ♀, antenna, lateral view of same antenna as in Figure 32, photographed as an analog (on-line) image, at 2048 X 2048 pixels and a resolution limited only by the film used. (**34**) Mymaridae, *Anagroidea* sp. ♂, head, semi-dorsal view of same head as in Figure 30, with stage tilted at 60° showing grey background. (**35**) *Anagroidea* sp. ♂, head, dorsal view of same head as in Figure 30, with stage tilted at 80° showing white background. (**36**) Trogositidae, *Ostoma ferruginea* (L.), (Coleoptera), thorax, dorsal view of punctations viewed flat on. (**37**) *O. ferruginea*, thorax, dorso-lateral view of same punctations as in Figure 36 but viewed at an angle.

and a resolution limited only by the film used (Fig. 33). Except for figure 32, all micrographs in this paper were taken as analog images. Improved computer digitizing technology and the use of appropriate software for manipulating images will be another tool useful in producing high quality micrographs.

If the stubs are to appear as backgrounds in the micrographs, then the stage holding the stubs should be kept on a horizontal plane to help maximize uniformity of the black background (Fig. 31). As the stage is tilted forward (toward the SEM's electron collector), the tape surface will become progressively lighter (Fig. 34) until, at an 80° tilt, it appears white (Fig. 35). At 90°, the extreme end of the forward tilt, the specimen will have the black void of the SEM's chamber as background. This is useful in obtaining black backgrounds but produces images with lower resolution if the specimen has been gold coated only from the top, and\or bottom, as there will be less gold on the sides. Gold coating the sides of the specimens will remedy this deficiency.

Specimens were turned, by rotating the stage, until their perimeters were as evenly illuminated as possible without losing the desired aspect. Even illumination reduces the harsh differences between otherwise dark and bright areas and permits an acceptable increase of overall contrast levels, which also helps to create the desired black backgrounds. The broadest range of stage rotation could be used if the stub was horizontally oriented, enabling the specimen to remain in the desired plane while being rotated. The scan rotate feature was then utilized to position the image on the screen.

Image distortion is a concern when using some older model SEM's where astigmatism cannot be fully corrected. This distortion increases as the stage is tilted; positioning the stage on a horizontal plane can help reduce image distortion. The Zeiss DSM 940A demonstrated virtually no distortion regardless of the viewing angle.

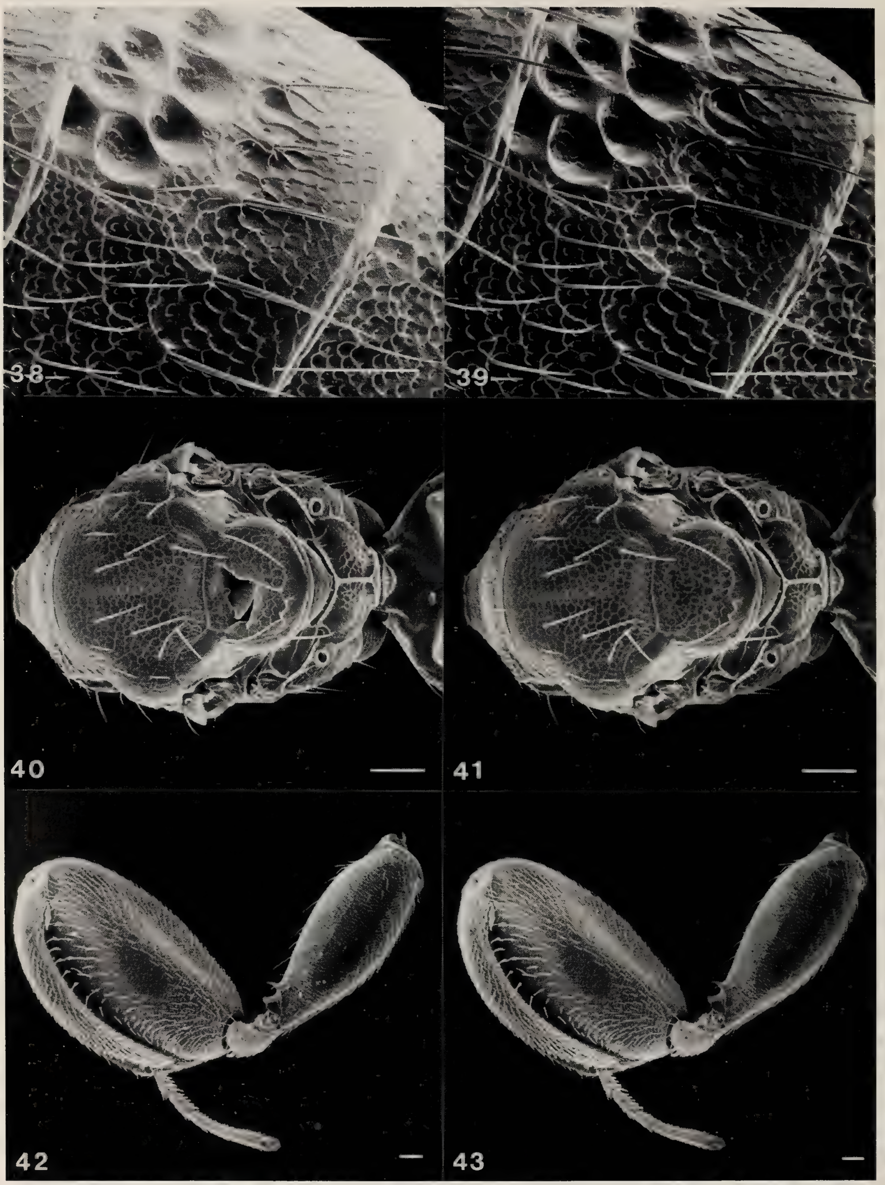
Rotating or tilting specimens toward or away from the beam will influence the highlights and shadows of uneven surfaces (e.g., punctate sculpture). These uneven surfaces (Fig. 36) can be accentuated (Fig. 37) by positioning the specimen such that the beam strikes the sculptured areas at a steeper angle. This process works on the same principle as using light as the source of illumination in photography. The stage should be tilted and rotated until the desired affect is achieved.

Dark room and photo preparation techniques

The preferred film used was Kodak T-MAX® 100 Professional black and white film. It is extremely fine grained with a high resolving power. T-MAX® developer was exclusively used for developing the T-Max® film. The films were usually developed on longer than normal time schedules so as to achieve 10% higher than normal contrast levels.

Ilford multigrade III RC photographic paper was used, with Nos.2½–4½ filters in the enlarger. Dodging and burning techniques (Schaefer 1983) were employed during printing (Fig. 39) to help achieve evenly black backgrounds, and to compensate for excessively bright areas on the images (Fig. 38).

Spotone® (manufactured by Retouch Methods Co., Inc.), can be used to touch up the finished micrographs (Schaefer 1983). This product is useful for touching up small irregularities on micrographs which need to be darkened. To correct unwanted tears in specimens (Fig. 40), which always leave dark shadows, appropriately sized and shaped paddles (small cardboard pads glued onto the ends of thin sticks) were moved around over the damaged areas while printing or the damaged areas were blackened on the negatives with a fine felt. This left corresponding white areas on the prints which were later darkened with Spotone® to blend with the surrounding tissue (Fig. 41). Any dirt, which might have escaped the cleaning efforts, will usually appear as white



FIGURES 38–43. **(38)** Ormyridae, *Ormyrus vacciniicola* Ashmead ♀, abdomen, lateral view, printed without using dodging techniques. **(39)** *O. vacciniicola* ♀, abdomen, lateral view, printed from negative used in Figure 38, showing effects of dodging during printing. **(40)** Eulophidae, *Dimmockia* sp. ♀, thorax, dorsal view, showing tear in center. **(41)** *Dimmockia* sp. ♀, thorax, dorsal view, printed from negative used in Figure 40, showing print touched up with Spotone. **(42)** Chalcididae, *Conura albifrons* (Walsh) ♀, hind leg, lateral view, with specks of dirt. **(43)** *C. albifrons* ♀, hind leg, lateral view, printed from negative used in Figure 42, with specks touched up with Spotone.

specks on the micrographs (Fig. 42). These specks can be eliminated with Spotone® (Fig. 43). Lighter spots in the black backgrounds can either be burnt in while printing or later filled in with a black felt pen.

Spot Off® (manufactured by Retouch Methods Co., Inc.) can be used to lighten up areas or unwanted dark spots. It is available as a kit of three solutions: bleach; an accelerator, to speed up the bleaching action; and a neutralizer, to stop the action of the bleach when the required results have been achieved.

Images can also be scanned into a computer either as a negative or a positive. With appropriate software these images can be manipulated to eliminate unwanted dirt, darken backgrounds, and enhance contrast, etc. The resulting image can then be printed with a high resolution printer or rephotographed producing excellent results.

Touch-up or manipulation of images must be done with care to avoid incorporating erroneous information or accidentally deleting information.

Discussion

The process for obtaining high quality SEM micrographs of minute arthropods requires numerous steps, from initially obtaining clean, intact specimens to final preparation of micrographs. Care must be taken to perform each step correctly, in particular to prevent soiling or damaging the specimens, as mistakes in one step can be only partially corrected in subsequent steps. The techniques described here ensure that good micrographs showing different aspects of a single specimen (by repositioning onto new stubs) can be successfully obtained on a regular basis, an important consideration when material is limited. The difficult and precarious task of mounting specimens on the ends of raised projections (as was illustrated by McGinley 1986; Eisenbeis and Wichard 1987) can be avoided. Additionally, even minute specimens can be safely manipulated, cleaned, dissected, and mounted. The need for tilting the SEM stage to 90°, in order to use the void of the SEM chamber, is no longer the only technique available to achieve a uniform black background. Micrographs of entire specimens (Figs. 44-48) or parts thereof can be easily made without any visible point of attachment (as was illustrated in Eisenbeis and Wichard 1987) by eliminating all background distractions.

The techniques described herein makes it easier to obtain a series of uniformly high quality micrographs with exactly the same orientation for individual species and dissected parts in the group under study. These micrographs are useful for comparative morphological studies. Micrographs of small arthropods such as Pseudoscorpionida (Fig. 44), immature Araneae (Fig. 45), Anoplura (Fig. 46), Acari (Fig. 47), and Collembola (Fig. 48) were also successfully obtained using the techniques described.

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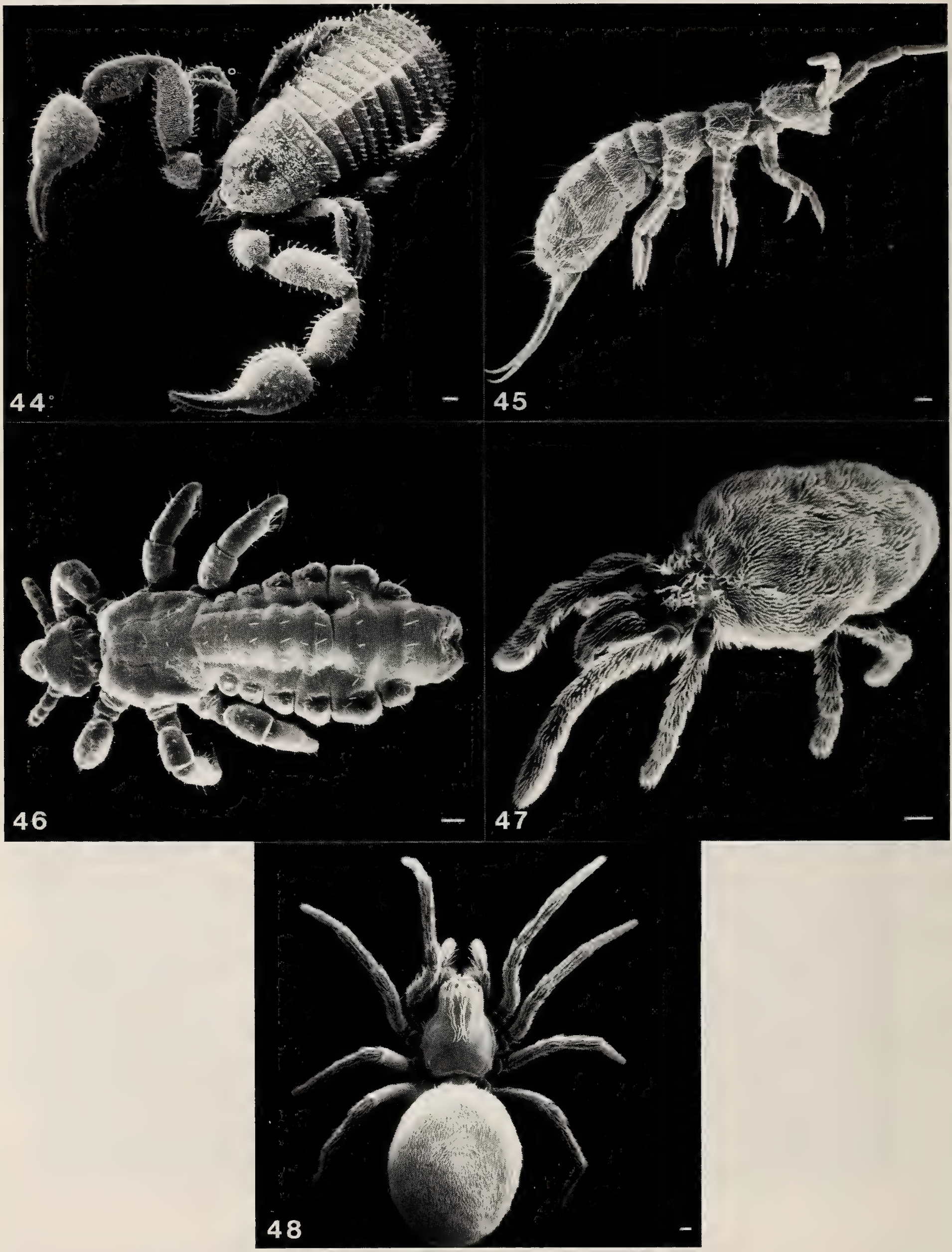

FIGURES 44–48. (**44**) Pseudoscorpionida (pseudoscorpion), dorsal view. (**45**) Collembola (springtail), lateral view. (**46**) Anoplura (sucking louse), *Pediculus humanus* L., dorsal view. (**47**) Acari (mite), semi-lateral view. (**48**) Araneae (spider), immature, dorsal view.

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DIAPAUSE TERMINATION, SURVIVAL AND EMERGENCE OF PEPPER MAGGOTS OVERWINTERED UNDER NATURAL AND ARTIFICIAL CONDITIONS

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Abstract *Proc. ent. Soc. Ont.* 127: 89-97

Emergence of adult pepper maggots, *Zonosemata electa* (Say) (Diptera: Tephritidae), from pupae naturally or artificially overwintered outdoors at various soil depths (0-15 cm), or held in laboratory cold storage (3°C) for varying lengths of time (100-300 days), provided information on overwintering survival and termination of diapause. Ninety-three percent of naturally-overwintering pupae were found within 7.5 cm of the soil surface and 49% of these were found in the first 2.5 cm. Ten percent of pupae artificially buried 2.5 cm deep disappeared over winter, probably as a result of predation. Adult emergence varied with overwintering depth and declined with increasing overwintering soil depths. The greatest percentage of adult emergence among both naturally- and artificially-overwintering pupae was found in the 2.5-5.0 cm soil stratum. The average number of days and variation in adult emergence times at 25°C declined with increasing time (100, 150 and 200 days) in laboratory cold storage. Median adult emergence times at 20°C, as a function of increasing time (150-300 days) in cold storage, exhibited a sigmoid-like response pattern, decreasing from a high of 56 to a low of 46 days, during this period. Pupae exposed to laboratory cold periods of 150-180 days, typical of field conditions in southern Ontario, had median emergence times of 56 days that were similar to emergence times among naturally-overwintering pupae (55 days) collected from 0-15 cm soil depths on 11 April. Results of this study confirm the use of 1 April as an approximate time of diapause termination and initiation of temperature summation for application of a phenology simulation model to predict adult pepper maggot emergence in southern Ontario.

Introduction

The pepper maggot, *Zonosemata electa* (Say), is a native North American tephritid (Bush 1965) with a geographic distribution extending from Florida to Ontario (Anonymous 1959). Horsenettle, *Solanum carolinense* L. (Family: Solanaceae), is a common weed and natural host plant of pepper maggot in southern Ontario (Foott 1968) but, occasionally, pepper maggots infest and cause economic damage to peppers and eggplants (Peterson 1923; Benjamin 1934; Burdette

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1955; Foott 1963, 1968). In Essex county adult pepper maggots emerge in early summer (Judd *et al.* 1991) and fly to solanaceous host plants on which they mate before ovipositing in the fruits. Eggs hatch about 10-12 days after being laid and larvae mine the developing fruits, where they complete development before entering the soil to pupate. Pupation begins in late August and all larvae have usually completed pupation by 1 October. Pepper maggot is univoltine and overwinters as a diapausing pupae (Judd 1994).

With no systemic insecticides available to control pepper maggot larvae feeding in fruit, its control in Ontario is directed at the adults using foliar insecticide sprays (Anonymous 1995). These production recommendations suggest that four sprays should be applied at weekly intervals beginning the last week of June. In spite of this prophylactic spray programme peppers can sometimes sustain high levels of damage, perhaps as a result of sprays being mistimed (Judd 1994). More precise spray timing could enhance the efficacy of insecticides and perhaps reduce the number of applications required.

Temperature-dependent development of pepper maggot pupae has been described (Judd *et al.* 1991) and this information should enable growers to predict adult emergence and time insecticide applications more accurately using either degree-day (DD) or simulation models. To use these temperature-driven phenology models effectively, growers and extension personnel need to know when to begin accumulating temperature sums. Often the dates used to initiate phenology models are chosen arbitrarily (Higley *et al.* 1986). A convenient calendar date, eg. 1 January or 1 April (Judd *et al.* 1991), is quite often chosen for simplicity, or starting dates are determined empirically by testing various dates to determine which date provides the least error of prediction (Judd and McBrien 1994). In temperate climatic zones where insects often diapause during winter, the most biologically relevant time to begin temperature summation may be when winter diapause is broken (Judd *et al.* 1993).

To date there has been no study of diapause termination in pepper maggot that could aid initiation of phenology models. The objectives of this study were to examine the effects of exposing populations of pepper maggot pupae to natural and artificial cold periods on the patterns of adult emergence. These patterns could provide an indication of when diapause is likely to terminate under field conditions. This information should reveal when it might be most appropriate to initiate temperature summation for use in phenology models (Judd *et al.* 1991). Information on the percentage of pepper maggot pupae overwintering at various soil depths and their survival was also collected to determine where best to measure soil temperatures used in phenology models and to understand more about the population dynamics of this little studied pest.

Materials and Methods

Insect Collection and Handling. Pepper and horsenettle fruits naturally infested with pepper maggot larvae were collected in early August 1987 from a planting of mixed pepper cultivars on the Agriculture Canada Research Station in Harrow, and a patch of horsenettle growing among soybeans south of the station, respectively. Several hundred fruits from each host plant were placed on pieces of coarse hardware screen and suspended over separate containers of potting soil in an environmental chamber set at 25±0.5°C with a 16:8 h L:D photoperiod. Mature larvae exited fruit and pupated in the soil. On 27 September 1987, pupae were sifted from the soil, washed in cold water, mixed with moist vermiculite and placed in a cold chamber (3±0.5°C).

Field Overwintering Studies. On 1 October 1987, 300 pepper-reared pupae were removed from laboratory cold storage and divided into 30 groups of 10. The remaining pupae were held in laboratory cold storage for use in various laboratory studies (see below). Five groups of 10 pupae were buried at each of 6 depths: 2.5, 5.0, 7.5, 10.0, 12.5 and 15 cm using a randomized block design with 5 m between blocks (replicates) and treatments (depths) within blocks. To facilitate burial and retrieval, all pupae were buried at their respective depths in 2 litre perforated (1 cm bottom holes) plastic pots which had been filled with Harrow sandy loam soil. Pots with pupae were buried on 2 October 1987, in a fallow, bare-soil field adjacent to the crop of peppers where larvae had been collected. Each pot was buried such that the upper rims were level with the surrounding soil surface and pupae were at their respective depths within the pots of soil.

Pupae were left to overwinter under these near natural conditions until 25 April 1988, when they were sifted from the soil, washed in cold water, placed on moist vermiculite in petri dishes and moved into a growth chamber set at 20°C and 65% RH with a 16:8 h L:D photoregime. Emergence of adults was recorded daily for 100 days, almost twice the expected median development time for post-diapause pupae held at 20°C (Judd *et al.* 1991). Puparia exhibiting no adult emergence after this time were dissected to determine if they were empty or contained a developing adult. The percentage of adult emergence as well as mean and median emergence times were calculated for groups of pupae overwintered at different depths. Data for males and females were combined because there is no significant difference in their developmental rates (Judd *et al.* 1991).

The depth at which pupae naturally overwinter was determined on the 11 April 1988. Four 1 m^2 quadrats were randomly laid down under previously (1987) infested pepper plants in the plot mentioned above. In each of these quadrats, the top 15 cm of soil was divided into six 2.5 cm strata and each stratum was sifted to remove all overwintered pepper maggot pupae. Pupae from each stratum were counted, washed in cold water and held separately in a 3°C cold chamber until 25 April 1988, when they were transferred to the same 20°C environmental chamber holding the collection of artificially-buried pupae. The percentage of adult emergence and the mean and median emergence times were determined for pupae collected from each stratum.

Laboratory Overwintering Studies. To study the effects of cold storage under more controlled conditions, 600 pepper-reared pupae, placed in cold storage on 27 September 1987, were divided into three equal groups. One group of 200 pupae was removed from cold storage and placed in a growth chamber set at 25°C and 65% RH with a 16:8 h L:D photoregime, after being held for 100, 150 and 200 days at 3°C, respectively. Total percent emergence and daily emergence was determined for each cold-storage treatment.

Miscellaneous Laboratory Emergence Studies. For a period of *ca.* one year after placing pupae in laboratory cold storage on 27 September 1987, various groups of pepper- and horsenettle-reared pupae were incubated at 20°C to produce adults for laboratory behavioural studies. The dates on which these pupae were removed from cold storage were noted and the emergence of individual adults recorded daily so as to know the exact age of each insect. Median emergence times for each of these groups were recorded and plotted against time in cold storage, which ranged from 150-300 days. These data provide additional information on the effects of varied overwintering durations on diapause termination and survival.

Statistical Analyses. χ^2 tests were used to compare the frequencies (counts) of adult emergence from naturally- and artificially-buried overwintering pupae across various soil depths (Zar 1984).

The relationships between the density and percent emergence or winter mortality and overwintering depths of naturally- and artificially-buried pupae were measured using simple Pearson product-moment correlations (Zar 1984). The mean development times (days) of naturally- and artificially-overwintered pupae were compared using a two-sample *t*-test (Zar 1984). All statistical tests were performed using an error rate of $\alpha = 5\%$.

Results and Discussion

Field Overwintering Studies. Most naturally overwintering pepper maggot pupae were recovered in the first 2.5 cm of soil and their density declined significantly ($r = -0.947$, $P < 0.05$) with increasing depth (Table I). With 94% of the overwintering pupae distributed throughout the top 7.5 cm of soil (Table I), temperature probes for monitoring pupal development should probably be placed at a 5 cm depth in future applications of a phenology model. Percent adult emergence from naturally-overwintered pupae was highest among those found in the 2.5-5.0 cm soil stratum (Table I). Ninety to 100% of the 50 pupae artificially-buried in each soil stratum in autumn were recovered in spring (Table I). The greatest disappearance of pupae was seen in the first soil stratum, but this disappearance declined with increasing soil depth. Although not studied directly, disappearance of artificially-buried pupae may be a measure of predation during the overwintering period. There was no significant difference (χ^2 test, df = 2, $P > 0.05$) in the frequencies of adult emergence from naturally- or artificially-buried pupae across the top three soil strata (Table I), indicating an equivalent mortality rate for both groups. Like naturally-overwintering pupae, adult emergence from artificially-buried pupae was highest in the 2.5-5.0 cm soil stratum (Table I) and below this stratum percent adult emergence declined significantly ($r = -0.827$, $P < 0.05$) with increasing soil depth. Mortality among pupae overwintering deeper in the soil might be expected to increase above levels reported here, if adults had to actually crawl through several cm of soil to reach the surface.

This combination of a tendency to pupate near the soil surface, a high disappearance of pupae near the soil surface, and reduced adult emergence among pupae overwintering in this first soil stratum, probably results in poor overwintering survival of pepper maggots in Essex county (Foott 1963). An inability to overwinter in sufficient numbers may be the major reason why pepper maggot is a sporadic rather than a chronic pest in southern Ontario, which represents the northern limit of this insect (Anonymous 1959; Bush 1965).

Average development times did not differ with overwintering depth in either naturally- or artificially-overwintered pupae (Table I), indicating that up to their times of recovery, developmental rates of pupae were similar at various depths. Throughout winter and up to *ca.* 11 April 1988, soil temperatures at all depths were below the post-diapause developmental threshold of 9.6°C (Judd *et al.* 1991). At each soil depth, however, the developmental times for naturally-overwintered pupae were *ca.* three days longer than artificially-overwintered pupae (Table I). In fact, mean development times of the two classes of pupae across the first three strata were significantly different (two-sample *t*-test, df = 2, $P = 0.0063$). As the median development time of naturally-overwintered pupae was 55 days (Table I), and the median development time of pupae incubated at 20°C is 55.9 days (Judd *et al.* 1991), these data suggest that naturally-overwintered pupae collected on 11 April 1988 had not yet undergone any post-diapause development. However, the fact that artificially-buried pupae remained in the soil an additional 14 days and had median development times of *ca.* 52 days, suggests they may have undergone some post-diapause development before laboratory incubation. This may have occurred because soil temperatures rose

TABLE I. Recovery, percent emergence and average development times at 20°C for pepper maggot pupae reared on peppers and artificially (AB) or naturally buried (NB) at varying depths in a fallow field over winter.

Soil strata (cm)	Number of pupae recovered[a]		Percentage of adult emergence[b]		Days to emergence			
					Mean (± SD)		Median	
	AB	NB	AB	NB	AB	NB	AB	NB
0.0 - 2.5	45	27	73.3	59.3	51.9 ± 0.3	55.2 ± 0.4	52	55
2.5 - 5.0	48	18	77.1	72.2	51.9 ± 0.3	54.9 ± 0.6	52	55
5.0 - 7.5	49	10	73.5	60.0	52.0 ± 0.2	54.5 ± 1.1	52	55
7.5 - 10.0	50	2	56.0	0	51.7 ± 0.3	-	51	-
10.0 - 12.5	50	2	66.0	0	51.6 ± 0.3	-	52	-
12.5 - 15.0	50	0	48.0	0	51.1 ± 0.3	-	52	-

[a] Number of AB pupae recovered out of 50 buried and number of NB pupae recovered per m^2 quadrat.

[b] Percentage emerging out of number recovered.

substantially during this period. This observation is consistent with the initiation of a phenology simulation model on 1 April (Judd *et al.* 1991).

Laboratory Overwintering Studies. Figure 1 illustrates the relative frequency of adult emergence from pupae incubated at 25°C after being held for increasing lengths of time in laboratory cold storage. These histograms indicate that sometime between 100 and 150 days at 3°C there is a marked change in the average developmental rates of each sample of pupae. With increasing time in cold storage there was a tendency for median development time to decrease from 55 days after 100 days of cold, to 31 days after 150 days of cold. Beyond 150 days in cold storage, median development time remained the same, but the range in development times decreased (Fig. 1).

Termination of diapause is a complex process that usually occurs at different rates in each individual, due to genetic variation and differences in the intensity of diapause (Tauber and Tauber 1976; Danks 1987). Outward indications of diapause termination are not always obvious in individual insects, although termination has sometimes been correlated with changes in individual respiration rates (Danks 1987). However, Tauber and Tauber (1976) noted that the average development time and variation of emergence times in populations of insects usually declines as more individuals in a population leave the diapause state. In various species (Judd *et al.* 1993; Judd and McBrien 1994), including tephritids (Brown and AliNiazee 1977), decreases in the proportion of diapause individuals in an overwintering population are often reflected by changes in the average emergence times in groups of insects sampled throughout winter.

A plot of the median emergence times of pepper- and horsenettle-reared pupae incubated at 20°C after increasing random periods of cold storage, produced a sigmoid-like pattern with a negative slope (Fig. 2). There appears to be an upper asymptote of median development times

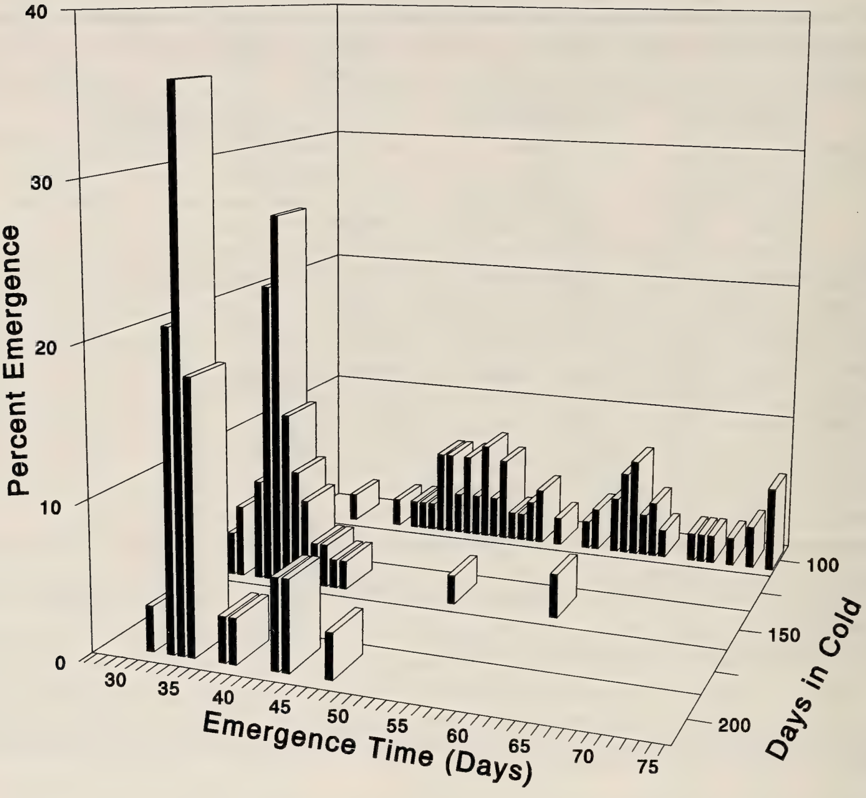

FIGURE 1. Relative frequency histograms for emergence times of adult pepper maggots incubated at 25°C following pupal storage at 3°C for 100, 150 and 200 days.

occurring between 150 and 180 days in cold, decreasing median development times for pupal populations stored between 180 and 250 days, and a lower asymptote for pupae held in cold for greater than 250 days (Fig. 2). Brown and AliNiazee (1977) observed a similar reduction in average development times of the western cherry fruit fly, *Rhagoletis indifferens* Curran, with increasing time in cold storage. However, in *R. indifferens* there was no upper asymptote and the lower asymptote was reached after 200 days in cold.

The upper plateau in Figure 2 is identical to the median development time reported by Judd *et al.* (1991) for pupae incubated at 20°C after 150 days of cold storage; consequently, 56 days probably represents an average developmental time for pupae incubated at 20°C anytime between 150 and 180 days after pupation. Declining development times in pupae stored at 3°C for longer periods (180 and 250 days) might be explained by the fact that although the lower developmental threshold was estimated to be 9.6°C, development still continues at temperatures below this threshold because the developmental curve is nonlinear and only approaches zero development asymptotically (Judd *et al.* 1991). However, using this argument, it is difficult to explain why

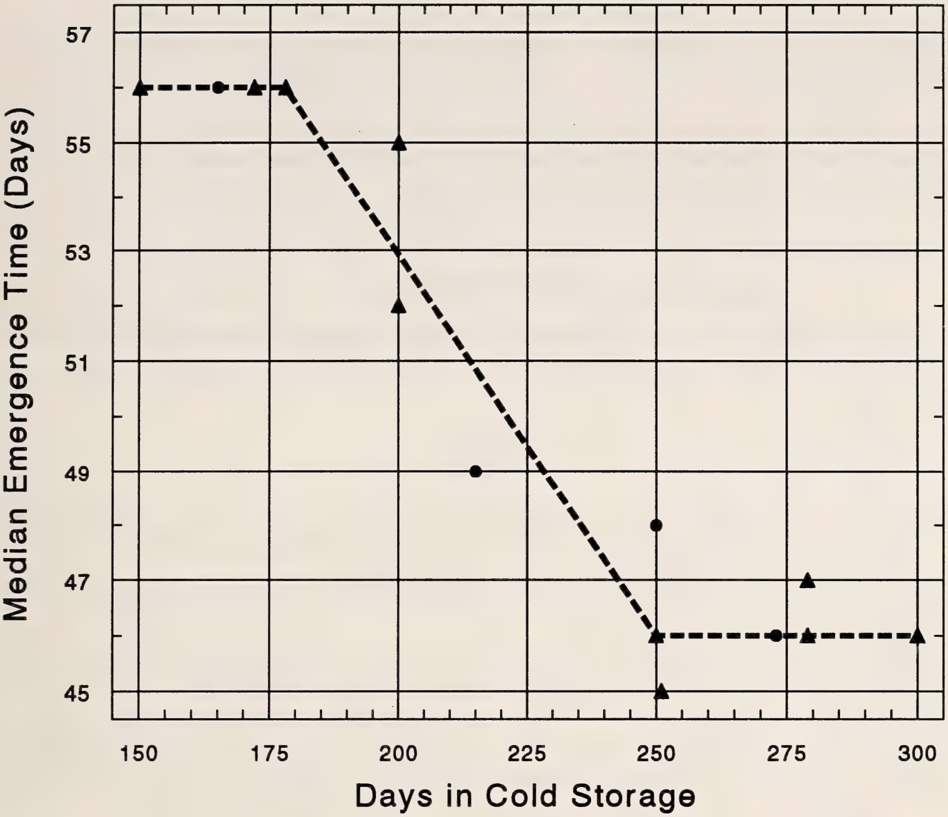

FIGURE 2. Plot (curve fitted by eye) of median adult emergence times for pepper- (▲) and horsenettle-reared (●) pepper maggots incubated at 20°C after pupal storage at 3°C for varying lengths of time.

development times do not continue to decrease with storage times longer than 250 days (Fig. 2). An alternative explanation for Figure 2 might be that a lower asymptote at 46 days represents the true median post-diapause development time at 20°C and the decline between 180 and 250 days represents the normal cessation of diapause and synchronization of the emergence times.

If this latter explanation is correct, then the developmental times reported by Judd *et al.* (1991) are probably somewhat higher than the true post-diapause development times. However, under normal field conditions in southern Ontario, 180 days would represent the average number of days a pepper maggot pupae might be exposed to temperatures below a developmental threshold of 9.6°C. This is based on the assumptions that most pupae enter diapause by 1 October and soil temperatures begin to rise above the developmental threshold around 1 April (Judd *et al.* 1991; Judd 1994). In an extremely rare cold year, or for pupae overwintering below 10 cm of soil, 240 days in cold storage probably represents an upper limit of natural cold exposure. For practical purposes, therefore, the developmental curve presented by Judd *et al.* (1991) is descriptive of temperature-dependent development in a population of pupae as they are likely to be found around

1 April, *ca.* 180 days after pupation. This may explain why a simulation model based on this curve and arbitrarily initiated 1 April predicted emergence of pepper maggots accurately in Essex county (Judd *et al.* 1991).

The results of this study provide biological evidence to support the idea that most pepper maggots are out of diapause by 1 April and confirm use of this date in initiating a phenology simulation model for predicting pepper maggot emergence in southern Ontario.

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ECOLOGICAL INTERACTIONS OF TARSONEMID MITES IN APPLE ORCHARDS: PREDATION OF APPLE RUST MITE AND USE OF *PHYLLONORYCTER BLANCARDELLA* MINES

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Abstract *Proc. ent. Soc. Ont.* 127: 99–106

Tarsonemid mites and the phytophagous mite *Aculus schlechtendali* Nalepa (Acari: Eriophyidae), the apple rust mite (ARM), are widely found in apple orchards; however, the nature of their interactions is not well known. In Ontario, populations of ARM are at their peak from mid-July to mid-August. Immediately after, they decrease rapidly and by mid-September the ARM populations are virtually absent from the apple foliage. From 1993 to 1995 an orchard was studied where four species of Tarsonemidae were identified. Two conclusions are reported here: 1) *Dendroptus* n. sp. near *suskii* Sharonov and Livshits was identified as a predator of the ARM, contributing partially to the mid-summer decrease of the ARM population, and 2) the existence of a close ecological relationship between two species of *Tarsonemus* and *Phyllonorycter blancardella* Fabricius (Lepidoptera: Gracillariidae).

Introduction

The apple rust mite (ARM), *Aculus schlechtendali* (Eriophyidae), is a phytophagous mite widely found in apple orchards in great numbers (sometimes over a thousand motiles/leaf); however, the ARM rarely produces economic damage in southeastern Ontario, in contrast to the detrimental effects on the apple foliage and development of resistance in some areas of Europe and some parts of USA (Childers *et al.* 1996). In fact, the early presence of ARM in apple orchards contributes to the build-up of predatory phytoseiid and stigmaeid mites early in the season (Thistlewood *et al.* 1996). Hence, Clements (1991) called them a 'beneficial pest', and Croft and Hoying (1977) defended the early ARM presence because their early feeding limits the potential development of European red mite populations.

Species of the Tarsonemidae are also present in apple orchards. In spite of their ubiquity and abundance on apple leaves, little is known of their ecology. Many tarsonemids are well known for being fungivorous; a few species like the cyclamen mite (*Phytonemus pallidus* (Banks)) are serious pests on strawberry fields, and others are associated with leaf deformations to some plants, similar to the ones produced by Eriophyidae (Lindquist 1986). Some tarsonemid species are reported as appropriating eriophyid leaf galls on a variety of broad leaved trees. *Tarsonemus confusus* Ewing on apple foliage also serves as prey for the predatory mite *Amblyseius fallacis* Garman (Phytoseiidae) (Schroyer 1994).

The objective of this study was to identify the tarsonemid species prevalent on apple foliage and their respective ecological roles.

Materials and Methods

Period and place of research. The research was conducted from May 1993 to September 1995 in an apple orchard on the now defunct Smithfield Experimental Farm of Agriculture Canada, 20 km west of Trenton, Ontario. The apple cultivar variety was Paulared on MM106 root stock, planted in 1979. The orchard was surrounded by grassy fields to the east and west, and research apple orchards 30 and 50 m away from the respective south and north edges. The orchard consisted of six rows of trees (3 to 3.5 m high). The trees were spaced out 3 m apart in rows 10 m apart.

Management of the apple orchard. The entire orchard received a management programme similar to commercial apple orchards in the Trenton region, with standard cultural practices on fertilization, pruning and mowing. Herbicides were not used. The entire orchard received a spray programme (Table I) which is compatible with integrated pest management (IPM) for control of pests other than the spotted tentiform leafminer (STLM) and phytophagous tetranychid mites (Anonymous 1990).

Experimental Design. The orchard was used for a series of IPM experiments including various regimes of pesticide use and predator release for the management of STLM and *Panonychus ulmi* Koch and *Tetranychus urticae* Koch. This required extensive sampling of the entire mite and insect fauna on the foliage of both experimental and control trees. For more detailed information see Villanueva (1996). Here, the population dynamics of tarsonemid mites and ARM are reported from the control trees.

Data Collection. The apple trees were sampled, on average, biweekly from June to October in each of the three years of the study. At each sampling, 10 randomly selected leaves/tree were taken from the designated trees in each of 1993 and 1994, and 20 leaves/tree in 1995. The collected leaves were placed in polyethylene bags, sealed and held in a cooler with an ice pack for transport to the laboratory. Later they were stored at 4-5°C in a refrigerator until each leaf was examined under a dissecting microscope at 40X magnification. Motile tarsonemid and eriophyid mites were recorded from both sides of the leaf, and STLM mines were examined. All counts were expressed as individuals per leaf, for individual trees.

For each collection date in 1995, approximately 1 out of every 20 sample tarsonemids collected were mounted onto permanent slides and sent for identification and lodging of voucher specimens to the Centre for Land and Biological Resources Research of Agriculture and Agri-Food Canada; Dr. E. Lindquist identified the specimens.

Results

The species of tarsonemid mites identified from samples taken in 1995 were *T. confusus*, *T. nodosus* Schaarschmidt, *T. waitei* Banks, and *Dendroptus* n. sp. near *suskii*; *A. schlechtendali* (ARM) was the only eriophyid mite.

The ARM were at their peak population densities by mid-July in 1993, and in 1994 the highest number of ARM was recorded by the first week of August (Fig 1). The number of ARM was not recorded in early July of 1995 (the presumed ARM population peak is represented by the

TABLE I. List of pesticides used in the apple orchard from 1993 to 1995. Pyrethroids were not sprayed in the control plots.

Year	Date	Pesticide Used	Rate (kg/ha)	Target
1993	May 14	mancozeb	3.4	apple scab
	May 26	mancozeb	3.3	apple scab
	June 3	mancozeb	6.1	apple scab
		azinphosmethyl	2.1	foliage caterpillars
	June 14	mancozeb	5.9	apple scab
	June 23	mancozeb	5.9	apple scab
	June 10	naphthalene-acetic acid	0.602	(*)
	June 23	phosmet	3.8	codling moth, apple maggot
1994	May 16	mancozeb	1.7	apple scab
	May 20	mancozeb	5.9	apple scab
	May 31	mancozeb	5.9	apple scab
	June 6	mancozeb	5.9	apple scab
		azinphosmethyl	2.1	foliage caterpillars
	June 13	mancozeb	5.9	apple scab
	June 22	mancozeb	6.9	apple scab
	June 28	mancozeb	5.9	apple scab
		azinphosmethyl	2.1	foliage caterpillars
	June 9	naphthalene-acetic acid	0.336	(*)
	July 18	phosmet	2.9	codling moth, apple maggot
	August 8	phosmet	2.1	codling moth, apple maggot
1995	April 28	metiran	5.9	apple scab
	May 4	metiran	5.9	apple scab
	May 15	metiran	6.9	apple scab
	May 23	metiran	5.9	apple scab
	June 6	captan	4.5	apple scab
		azinphosmethyl	2.4	foliage caterpillars
		naphthalene-acetic acid	0.292	(*)
	June 15	captan	3.8	apple scab
	June 22	captan	3.6	apple scab
		azinphosmethyl	2.4	foliage caterpillars
	July 6	captan	3.1	apple scab
	July 13	phosmet	3.1	codling moth, apple maggot
	August 3	phosmet	3.1	codling moth, apple maggot

(*) Naphthalene-acetic acid (NAA) is a plant growth regulator compound.

broken lines, following the pattern of 1993). During each of the three years, the ARM populations decreased rapidly by mid-August and totally collapsed by September.

In 1993 the tarsonemid mites had two discernible peaks — the first one matching the peak of ARM by mid-July and a second, much higher, one by September (Fig. 1). A similar assumption

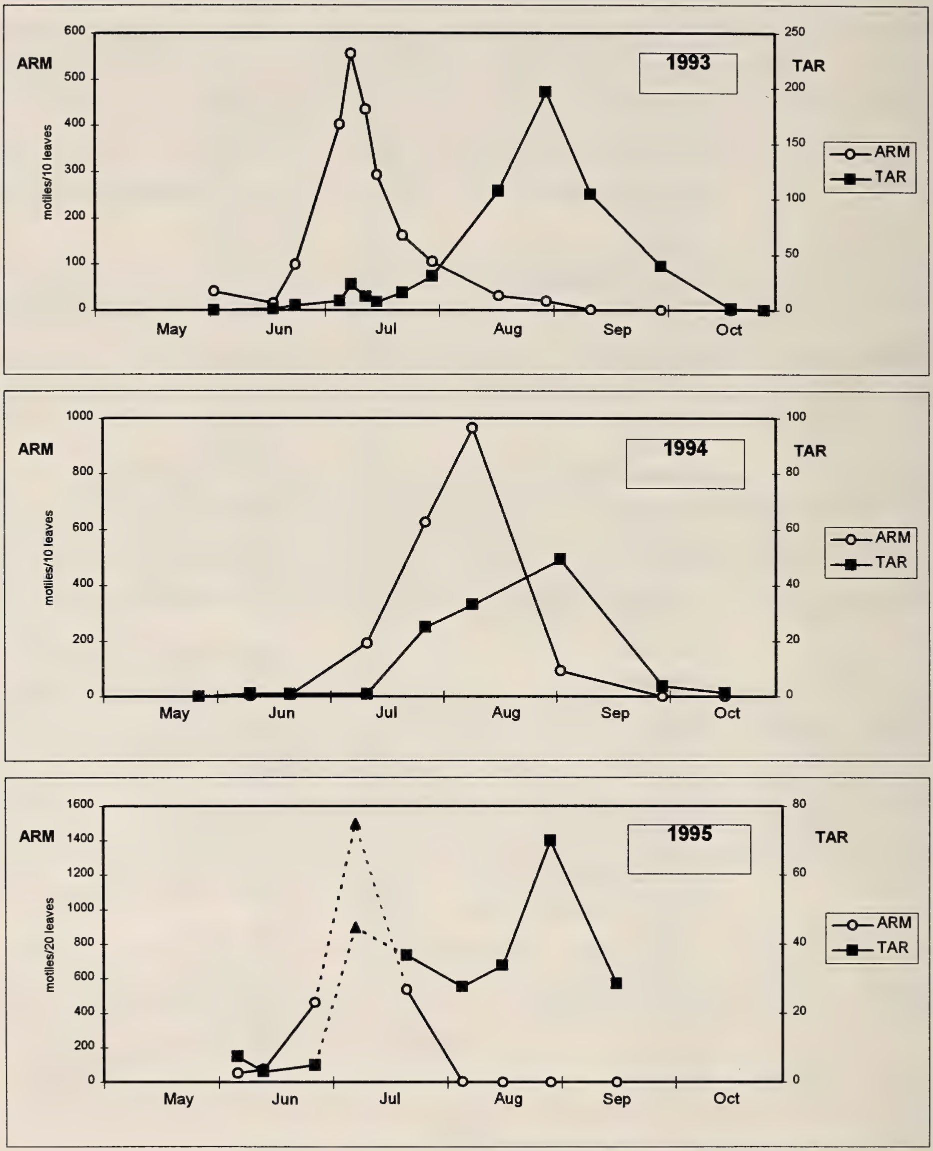

FIGURE 1. Population densities of *Aculus schlechtendali* (ARM) and tarsonemid (TAR) mites from 1993 to 1995. (▲) Represent the presumed ARM and tarsonemid (TAR) population peaks for 1995.

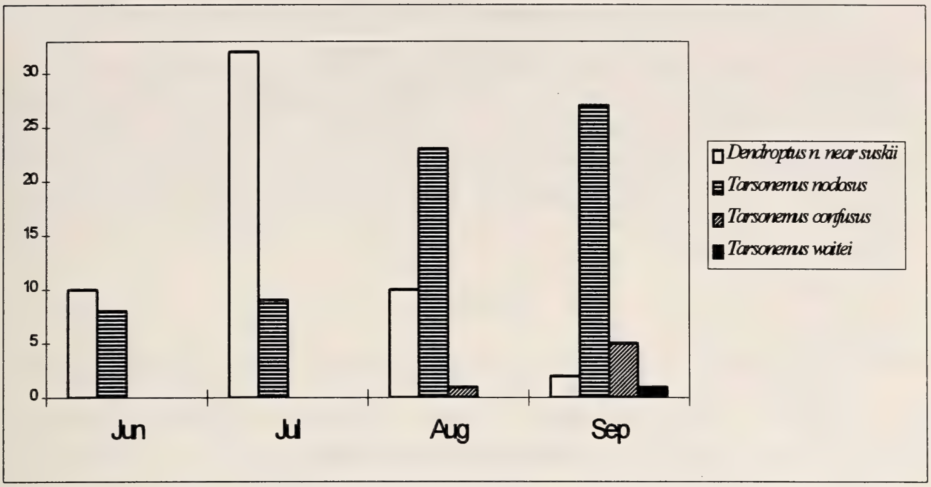

FIGURE 2. Abundances of identified tarsonemid species in 1995.

can be made for 1995 (broken lines) in spite of the lack of data for early July. In 1994 the tarsonemid densities did not show a double peak.

T. nodosus was present throughout the season in 1995, while *T. confusus* and *T. waitei* appeared only in August and September (Fig. 2). The first tarsonemid peak corresponds to the highest number of identified *Dendroptus* n. sp. near *suskii* in July and the second peak coincides with the highest number of identified *T. nodosus* in August and September (Figs. 1–3).

Discussion

Results from 1993 and 1995 clearly show that the first increase of tarsonemid populations coincided with the peak of the ARM and with the highest number of *Dendroptus* n. sp. near *suskii*. Observations in the lab showed that *Dendroptus* n. sp. near *suskii* prey on ARM motiles on leaf discs. This species was identified from apple orchards in Quebec as *Dendroptus forestae* n. sp. by Lindquist (Forest *et al.* 1982), who later placed it as a species near *Dendroptus suskii*, which was previously described in the Crimea (Ukraine) feeding on tydeid eggs (Mitrofanov *et al.* 1986). *Dendroptus* n. sp. near *suskii* was not sufficiently abundant in any of the three years to contribute in a major way to the late summer decline of ARM. A combination of phytoseiid and stigmaeid predation and a fungal pathogen appear to be the main factors for the population decline; by September the remaining ARM migrated off the leaves. However, the decline of *Dendroptus* in late summer can be seen as a response to the decline of the ARM.

T. nodosus, T. confusus, and *T. waitei* have been reported in apple orchards previously (Suski 1965; Lindquist 1978, 1986; Forest *et al.* 1982; Kaliszewski *et al.* 1983). *T. nodosus* is a widespread tarsonemid mite in Ontario apple orchards. It was previously identified as *Tarsonemoides pomi* (Suski 1965), and its continuous presence from June to September indicates

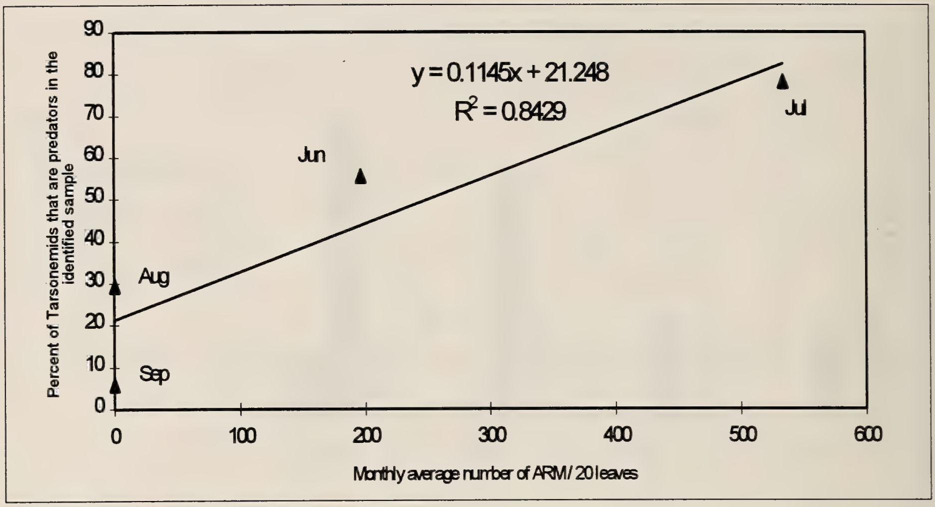

FIGURE 3. Plot of the percents of tarsonemid mites that are predators in the identified sample (*Dendroptus* n. sp. near *suskii*), and monthly average of ARM/20 leaves.

a prominent association with apple foliage. The increase of *T. nodosus* in August and September and the appearance of *T. confusus* in the orchard is associated with the opening of old STLM mines. Concentrations of both eggs and motile forms of these two species were frequently found in old STLM mines. This habitus probably provides protection against predators, relatively stable and more humid environmental conditions and abundant fungal resources (growing on STLM frass and decaying leaf tissue) for the mites.

The presence of a single *T. waitei* in the apple orchard late in the season might be circumstantial; however, this mite is primarily a fungivorous mite, and has, in some occasions, been misidentified. Previous studies suggested that *T. waitei* might be a facultative phytophagous species because it was found on peach (*Prunus*) and sugar maple (*Acer*) leaves with foliar deformities similar to those caused by eriophyids (Lindquist 1978).

The absence of a double peak in the tarsonemid population in 1994 is probably due to the ARM peak population being three weeks later than in 1993 and 1995. By that time old STLM mines were decaying, resulting in a population overlap between *Dendroptus* which preyed on the ARM, and *Tarsonemus* spp. which increased their populations inside the mines. The use of mancozeb (Table I) may explain the delay of the ARM peak in 1994, since this fungicide has been reported as giving good control of ARM (Easterbrook 1984). Climatic conditions (temperature and precipitation) appear not to have been an important factor in this regard because meteorological conditions were similar in 1993, 1994 and 1995.

This study identified and described four species of tarsonemid mites found on foliage in an apple orchard. One of them, *Dendroptus* n. *sp.* near *suskii* Sharonov and Livshits, is a predator of primarily the ARM; the other two abundant species of tarsonemid mites (*T. nodosus* and *T. confusus*) appear to be fungivorous, and are concentrated in old mines of STLM (*Phyllonorycter blancardella*). All four species can serve as alternate prey for phytoseiid predators. More studies are necessary to better understand the role of tarsonemid mites in the apple orchard.

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REMOVAL OF DROPS FROM APPLE ORCHARDS: POTENTIAL IMPACT ON BUILDUP OF APPLE MAGGOT FLIES (DIPTERA: TEPHRITIDAE)

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Abstract

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Every other week beginning usually four weeks before harvest and ending at or about two weeks after harvest in 1993 and 1994, batches of drops were removed beneath trees of four apple cultivars in a commercial orchard, placed beneath non-bearing apple trees, and examined weekly for characteristic holes in the fruit skin signifying exit of apple maggot larvae and the potential for buildup of within-orchard apple maggot populations. The four cultivars sampled ranged from early-ripening (Jersey Mac) to mid-ripening (McIntosh, Cortland) to late-ripening (Golden Delicious). In most cases, times of peak larval exit across sampled batches within a cultivar spanned a period of at least two to four weeks. In consequence, there was no case in which pickup of drops at a single point in time accounted for 80% or more of all larval exit holes found in all sampled drops collected beneath a cultivar. Maximum benefit of drop removal occurred about two weeks before harvest for all cultivars except Golden Delicious. Under current practice, most commercial apple growers who pick up drops do so only once: well after harvest for purposes of using drops for cider, a time of drop removal that has little effect on extent of within-orchard exit of apple maggot larvae. Because it would likely be prohibitively expensive for most commercial orchardists to pick up apple drops a second time (pre-harvest), we conclude that removal of drops beneath commercial orchard trees is not likely to be a commercially feasible approach to preventing within-orchard origin and buildup of apple maggot flies.

Introduction

The apple maggot fly, *Rhagoletis pomonella* (Walsh), is a key summer pest of apples in eastern and midwestern regions of North America. Ever since the advent of synthetic organic insecticides, most orchardists have been able to achieve effective control of apple maggot by applying two to four insecticide sprays during July and August. Recently, a behavioural approach to apple maggot control has been developed for use in large commercial orchards. It involves surrounding orchard blocks with odour-baited red spheres placed about 5 m apart on perimeter apple trees (Prokopy *et al.* 1990, 1996). The intent is to intercept flies immigrating from nearby unmanaged host trees and thereby prevent them from penetrating into the orchard interior. Flies alighting on the spheres are killed either through entanglement in a coating of sticky material on the sphere surface (Prokopy *et al.* 1990, 1996) or through ingestion of a coating of feeding stimulant and insecticide on the sphere surface (Duan and Prokopy 1995).

In a recent survey in Massachusetts, apple growers perceived several potential benefits arising from use of this behavioural approach to apple maggot management as a substitute for application of insecticide sprays (Prokopy *et al.* 1995). A potential shortcoming, however, is the danger that some flies will not be intercepted by the perimeter traps and will go on to oviposit within the orchard. Larvae developing within the flesh of infested apples could (following apple drop, larval exit, and puparial formation in the soil) give rise to adults emerging within the confines of the orchard next season, thereby compromising the value of perimeter interception traps.

One way to counter the potential deleterious effect of within-orchard fly emergence would be to pick up dropped apples before larval exit (very rarely do larvae exit from fruit hanging on the tree — Dean and Chapman 1973). Indeed, picking up drops was considered to be the most effective way of controlling apple maggot before the advent of inorganic insecticides late last century (Illingworth 1912). Toward this end, several researchers studied patterns of larval exit from drops of early, middle and late-ripening apple cultivars with the aim of pinpointing frequency of need for drop pick-up to prevent larval exit (Illingworth 1912; O'kane 1914; Brittain and Good 1917). None of these early investigators, however, studied patterns of larval exit from drops of important modern-day apple cultivars. Dean and Chapman (1973) did study larval exit patterns from drops of some contemporary cultivars but only from drops collected when the "earliest drops were seen under the trees."

Here, from a Massachusetts commercial orchard slightly infested by apple maggot flies, we collected drops of four prominent cultivars (Jersey Mac, McIntosh, Cortland and Golden Delicious) approximately every other week beginning usually about four weeks before harvest and ending at or about two weeks after harvest (depending on cultivar). These four cultivars span a range from early to middle to late-ripening. Our primary intent was to ascertain whether, for each cultivar, there was a single point during the time period spanned by our study that a grower could pick up drops and thereby ensure that the great majority of larvae infesting drops during that time span would be removed before exiting the fruit.

Materials and Methods

Slight infestation by apple maggot flies in the commercial orchard under study occurred as a consequence of suboptimal deployment of odour-baited red sphere traps, which permitted some proportion of flies to escape capture. In 1993 and 1994, ten trees of each cultivar were randomly designated for removal of drops. Ten drops per tree were removed on each sampling date and pooled to comprise a total sample of 100 drops for that cultivar on that date. To ensure that all drops removed on a given date had fallen only since the previous sampling date, we marked off a portion of the area beneath each of the ten sampled trees and on each sampling date removed all drops that had fallen into that area. In every case, enough fruit remained on the trees following harvest to provide samples two weeks after harvest.

Each batch of 100 sampled drops was placed on the ground beneath canopies of large (6 m diameter) non-bearing apple trees. Weekly, beginning on the day of acquisition, each batch of drops was examined carefully for evidence of larval exit holes. An exit hole has a characteristic appearance of torn apple skin surrounding the hole. To confirm that an apparent exit hole was in fact an exit hole, we cut the flesh beneath the skin and examined it for evidence of a characteristic larval trail. All suspected exit holes were confirmed, following which apples containing an exit hole were removed from the batch.

To gain maximum information from this study it would have been ideal to have counted the numbers of ovipositional punctures made by apple maggot flies in each batch of sampled drops. However, verification of such punctures would have required cutting into the fruit flesh beneath suspected punctures, risking harm to developing larvae. We chose not to do this. Similarly, it would have been ideal to have assessed the total number of larvae emerging from each batch of fruit, not simply the percent of fruit exhibiting a larval exit hole. For two reasons, we were unable to achieve this ideal. First, we lacked the resources necessary to collect all emerging larvae each week from each batch of fruit under conditions duplicating those beneath apple trees. Second, as already mentioned, verification of a larval exit hole required cutting into the fruit flesh, which could have adversely affected viability or development of larvae still present in the flesh.

Results

Data for each cultivar each year show that in nearly all cases, there was a peak time of larval exit from each batch of collected drops (Figs. 1, 2). As we expected based upon studies by aforementioned investigators, time of larval exit became progressively later as cultivar ripening time progressed from early (Jersey Mac) to mid (McIntosh, Cortland) to late (Golden Delicious) season. For each cultivar, peak larval exit did not coincide in time across all batches of drops sampled. In fact, in most cases, time of peak larval exit across sampled batches within a cultivar spanned a period of two to four weeks. For Jersey Mac and McIntosh, harvest occurred usually near the middle of this two-to-four-week period. For Cortland and Golden Delicious, harvest occurred near the end or after this two-to-four-week period.

When the data are presented in a different format, they show that within the time period spanned by removal of drops beneath trees of each cultivar, there was no case in which pickup of drops at a single point in time accounted for 80% or more of all larval exit holes found in all drops collected beneath a given cultivar in a given year (Figs. 3,4). For Jersey Mac, maximum prevention of larval exit in 1993 (72%) occurred when drops were picked up at harvest and in 1994 (64%) when drops were collected about two weeks before harvest. For both McIntosh and Cortland, maximum prevention of larval exit occurred when drops were picked up about two weeks before harvest: for 1993 and 1994, respectively, 56 and 75% for McIntosh and 56 and 65% for Cortland. For Golden Delicious, no pickup time in either 1993 or 1994 prevented more than 52% of larval exits.

Discussion

Our findings suggest that for each cultivar sampled, the span of exit times of apple maggot larvae from all batches of drops collected for that cultivar extended over a sufficiently great period so as to deny the possibility of a single drop removal date that would prevent more than 80% of larvae from exiting fallen fruit of that cultivar. Based on our data, the optimum period of drop removal would be about two weeks before harvest for Jersey Mac, McIntosh and Cortland, and two to three weeks before harvest for Golden Delicious.

We recognize that the proportion of dropped apples in a batch giving rise to larval exit represents only part of the equation describing the extent of within-orchard buildup of apple maggot populations. The other part is represented by the total numbers of drops in the population from which a sample batch has been taken. In theory, one ought to be able to determine the total

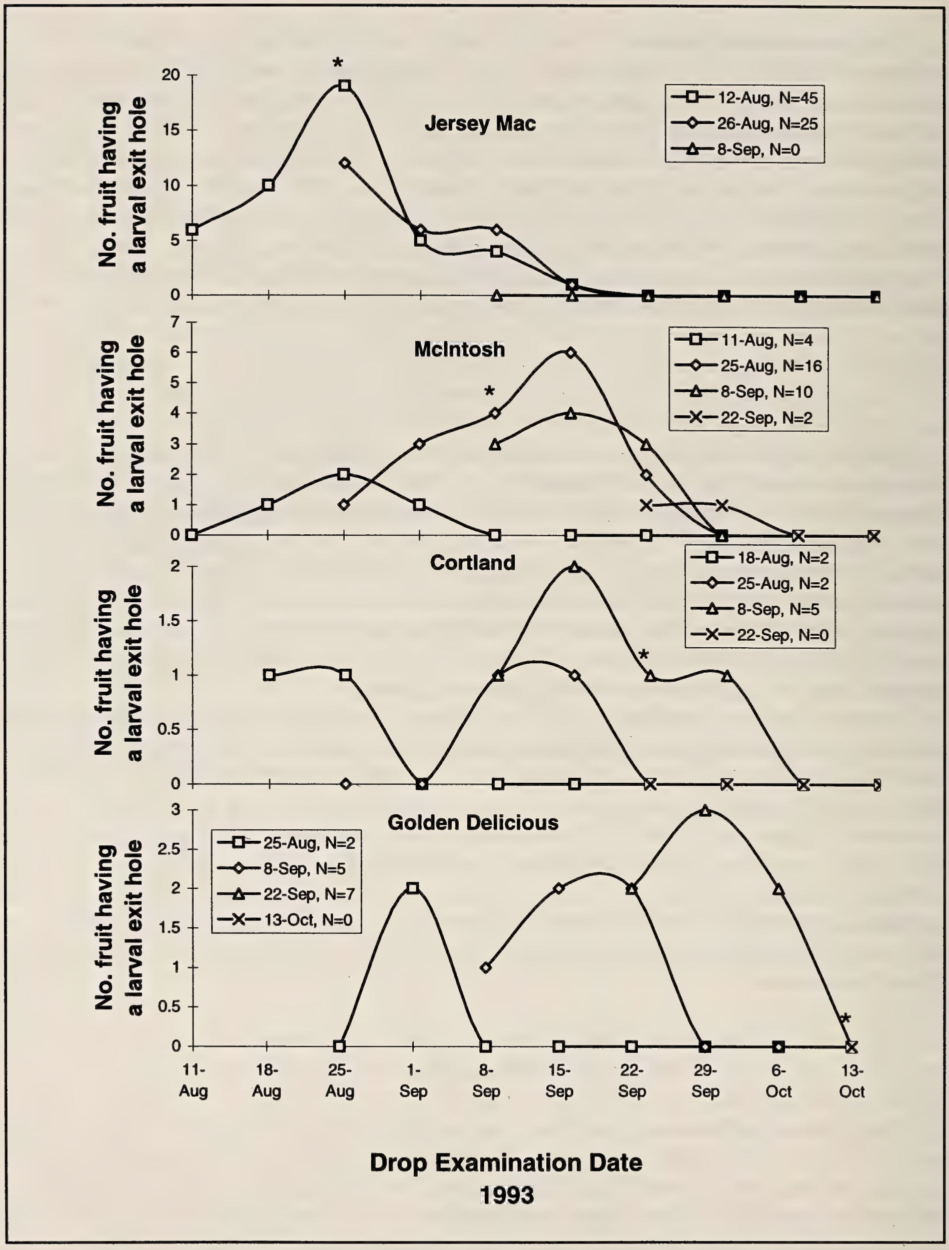

FIGURE 1. Number of fruit in each batch of 100 drops collected per cultivar per collection date in 1993 that showed a larval exit hole when collected or since the previous examination date. Dates of drop collection and total number (N) of fruit per batch with an exit hole are given in an insert for each cultivar. * = date of harvest.

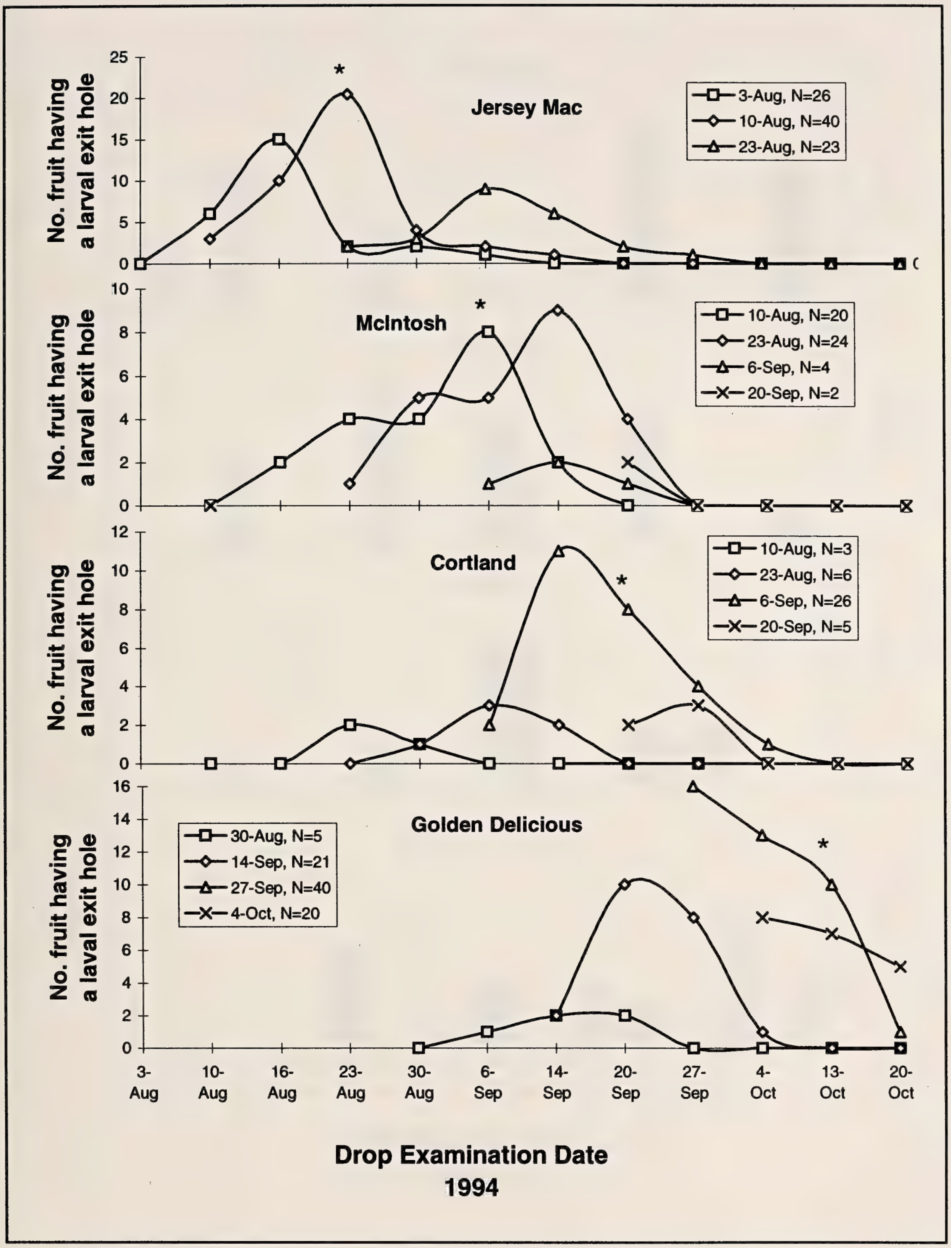

FIGURE 2. Number of fruit in each batch of 100 drops collected per cultivar per collection date in 1994 that showed a larval exit hole when collected or since the previous examination date. Dates of drop collection and total number (N) of fruit per batch with an exit hole are given in an insert for each cultivar. * = date of harvest.

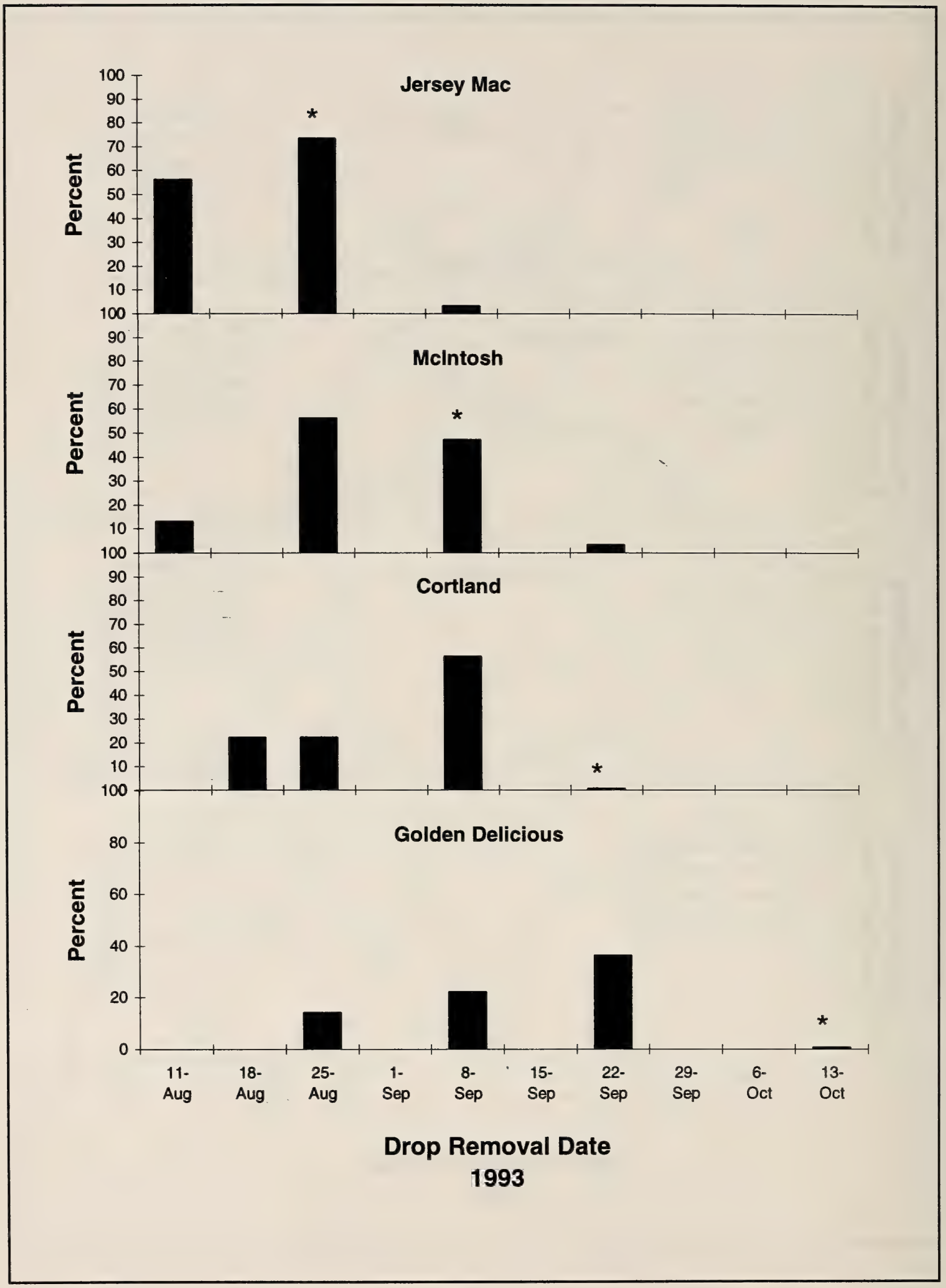

FIGURE 3. Of the total number of fruit exhibiting a larval exit hole (N) across all batches of drops collected beneath a cultivar in 1993, the percentage that could have been kept free of larval exit in the orchard by picking up drops on each respective collection date. * = date of harvest.

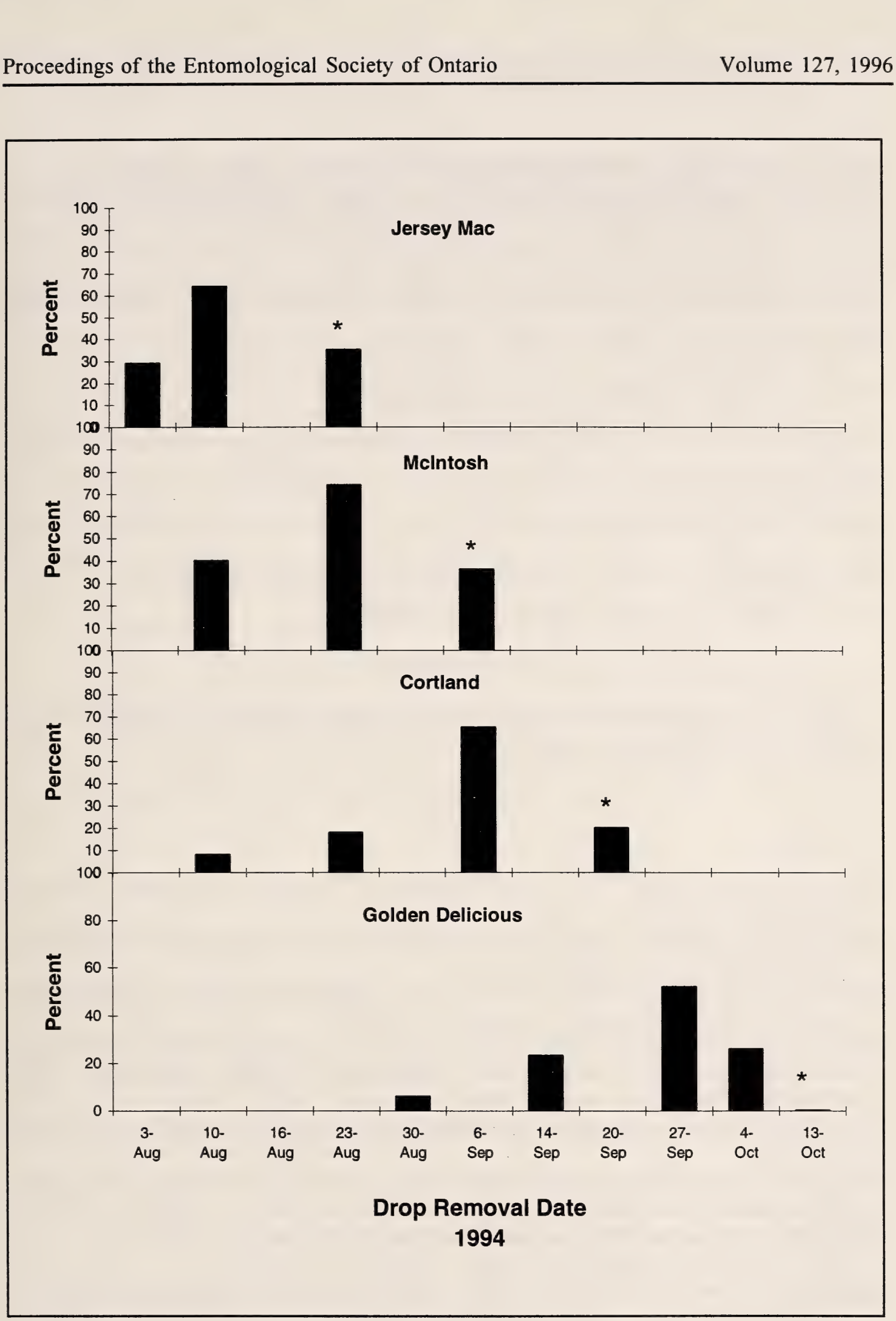

FIGURE 4. Of the total number of fruit exhibiting a larval exit hole (N) across all batches of drops collected beneath a cultivar in 1994, the percentage that could have been kept free of larval exit in the orchard by picking up drops on each respective collection date. * = date of harvest.

number of larvae forming within-orchard puparia by multiplying these two factors for each cultivar. The value of engaging in such an exercise for purposes of predicting optimal time of drop removal is strongly compromised, however, by uncertainties associated with the extent of apple drop at any given week preceding or during harvest. Temperature, rainfall and wind are important factors bearing upon the extent of apple drop during any given week. To illustrate, peak drop of McIntosh occurred about harvest in 1993 and 1994, but in 1995 it occurred about two weeks before harvest. Hence, we have chosen not to factor in the extent of drop in presenting our data.

Under current practice, most apple growers in eastern and mid-western North America either pick up drops once (well after harvest is completed for purposes of using drops for cider) or not at all. Drop removal is costly in terms of labor. Our data suggest that confining removal of drops to a period after harvest would accomplish little in terms of preventing within-orchard exit of apple maggot larvae from infested fruit. Would the expense of labor be justified in removing drops not merely once (after harvest) but a second time (two or more weeks before harvest)? We think not, especially in view of the probability that 20% or more of drops containing apple maggot larvae would escape removal. Therefore, for the future, we plan to place increased emphasis upon optimizing patterns of odour-baited red sphere trap deployment to preclude the need for removing drops to prevent within-orchard buildup of apple maggot.

Acknowledgment

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THE BIOLOGY, IMPORTANCE, AND BIOLOGICAL CONTROL OF *COLEOPHORA DEAURATELLA* (LEPIDOPTERA: COLEOPHORIDAE), A NEW PEST OF RED CLOVER IN NORTH AMERICA

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Abstract *Proc. ent. Soc. Ont.* 127: 115–124

A European species, *Coleophora deauratella* Lienig and Zeller was discovered as a new Canadian pest of red clover seeds at New Liskeard, Ontario in 1989. It is a univoltine species, which overwinters as mature, fourth-instar larvae within cases. An average infestation of 1 to 3 larvae/head at New Liskeard compared with a severe infestation reported in Denmark. The initial infestation in new heads destroyed 3.8 to 4.7% of the florets during bloom, and total seed loss was an estimated 80%. A European parasitoid, *Neochrysocharis formosa* (Westwood) (Hymenoptera: Eulophidae), was imported through quarantine facilities and released at Canfield and Guelph, Ontario.

Introduction

Specimens in museums indicate that *Coleophora deauratella* Lienig and Zeller has been in North America since 1962, but because of misidentifications it was only recently reported by Landry (1991). In addition to *C. deauratella*, several species of clover-infesting *Coleophora* are native to Europe. Two of these species, *C. mayrella* (= *spissicornis*) (Hübner), and *C. alcyonipennella* (Kollar), became serious pests of white clover seed production in New Zealand (Stuart 1958; Dumbleton 1963; Pearson 1980). *C. mayrella* occurs in North America (Smith and Andres 1954), as does *C. trifolii* (Curtis) which feeds on sweet clover (*Melilotus* sp.)(Landry 1991). Landry (1991) gives criteria for separating the three North American species.

Although red clover (*Trifolium pratense* L.) is the primary host, *C. deauratella* has been reported from stone clover (*T. arvense* L.), alsike clover (*T. hybridum* L.), zigzag clover (*T. medium* L.) and white clover (*T. repens* L.) (Hammer 1937; Markkula and Myllymäki 1960). The species has become well established in eastern Canada and in the northeastern United States (Landry 1991), and is of considerable concern to producers of red clover seed.

The biology of European populations of *C. deauratella* has been described from Finland (Markkula and Myllymäki 1960), and from Denmark under the incorrect name, *C. spissicornis* (Hammer 1937). The pest in Europe is univoltine and overwinters as mature larvae in their sealed cases. Adults emerge in mid-June and the larvae reach full maturity between mid-July and early September, depending on the temperature. Larvae feed within the corolla on developing seed and later tunnel into adjacent florets. Larger larvae may completely destroy the seed leaving only the seed coat (Markkula and Myllymäki 1960). Fourth instars construct cases out of florets, and move about over the flower heads feeding between the florets before moving to the ground and sealing their cases to overwinter.

Zwölfer (1961) reported on 14 organisms reared from *C. deauratella* on red clover in Europe. The concerted effort at biological control of coleophorids on white clover in New Zealand involving the International Institute for Biological Control was reviewed by Pearson (1989). Two species established from introductions in New Zealand and biological control was described as admirable. The most important of these species was, *Neochrysocharis formosa* (Westwood) (Hymenoptera: Eulophidae) (= *N. trifolii* (Erdös) and *Chrysonotomyia trifolii* (Erdös) of New Zealand literature). Zwölfer (1961) reported 21.4% parasitism of *C. deauratella* by this parasitoid in Europe.

Although the biology and importance of *Coleophora deauratella* has been inferred from European records (Landry 1991), this is the first economic report on this pest from North America. Our objectives were to confirm the life cycle in North America, to determine its economic importance in Ontario, and to initiate biological control.

Materials and Methods

Sampling

All sampling was done in fields of early flowering (double-cut) red clover grown for seed production. These fields were all located in the vicinity of New Liskeard, Ontario (47.5°N) where damaging populations were first discovered. The period when the adult moths were active in the field was determined from 3 replicates of 25 sweeps with an insect net in one field in 1989, and in three different fields in 1990. Sampling began on 5 July 1989 and on 22 June 1990, and continued both years at approximately weekly intervals until late August. Samples were stored in 70% alcohol, and sorted later under a light microscope. Fourth-instars were also collected in these sweep samples later in the season, and were counted in the 1990 samples.

To estimate larval infestations of *C. deauratella* in the flowers and the floret damage caused by them, samples of newly set, red clover heads were collected weekly from two fields from 21 July to 21 August 1989, and from two other fields from 27 July to 29 August 1990. Three samples of 12 randomly selected heads were collected from each field on each date in 1989 and four samples of 50 in 1990. Clover heads were preserved in Kahle's solution or 70% alcohol. Twelve heads/sample were dissected in 1989 and a subsample of 10 heads/sample in 1990. Numbers of larvae per head and the total numbers of florets and damaged florets were recorded. Damaged florets were classified as either containing a larva, or containing frass or a larval hole in the side of the floret.

Additional samples of mature clover heads collected at harvest time were dried and hand-threshed to assess the damage to mature seed. Ten samples of approximately 100 randomly selected seeds were evaluated for damage from each sample, and the amount of damaged seed was recorded as a percentage of the total.

Biological Control

Permits were obtained for the importation and release of *Neochrysocharis formosa* (Westwood) (Hymenoptera: Eulophidae). The hosts, *C. mayrella*, and *C. alcyonipennella*, were collected from white clover fields on the South Island of New Zealand near Tai Tapu. About 90% of the hosts were *C. mayrella*. Fourth-instar hosts of the first shipment were collected by sweeping white clover in early fall before the larvae moved to the ground to overwinter. Because of problems initiating and completing diapause and subsequent poor pupation and emergence in quarantine, the remaining three shipments were host cases collected from samples of leaf litter. Fields with hosts were identified by sweep sampling the previous summer. Cases with diapausing larvae were hand-picked from leaf litter in late fall to early spring. Populations of hosts were low in all of the collection fields.

The hosts were processed through quarantine facilities at the University of Guelph. Releases were made either of *C. deauratella* larvae that had been exposed to *N. formosa* in quarantine (first shipment) or *N. formosa* adults (remaining shipments). Two release sites were used, one in a commercial seed field at Canfield, Ontario (42°58'N; 79°45'W) from 1993 to 1995. The release field of common red clover was a flowering regrowth crop that was heavily infested with *C. deauratella*. Clover in the release area was left unharvested. The other release area was an unmanaged area near Guelph, Ontario (43°33'N; 80°18'W) in 1995. This site had been seeded to red clover three years earlier for erosion control and was severely infested with *C. deauratella*.

Results and Discussion

Population Dynamics

The earliest adults of *C. deauratella* were collected in sweep samples at New Liskeard (47.5°N) on 28 June 1990, and the latest on 9 August 1989 and 22 August 1990 (Fig. 1). This flight activity was later than in either Denmark (54 to 57.5°N) (Hammer 1937) or Finland (Markkula and Myllymäki 1960). Peak adult numbers occurred in mid- to late July at New Liskeard, but approximately a month earlier in both Denmark and Finland. One peak in moth activity both years (Fig. 1) confirms that the pest is univoltine. Red clover was in bloom when the first adults (Fig. 2A) were collected, and bloom extended throughout the ovipositional period.

As expected, peak larval infestation in new flower heads followed peak moth numbers. Larvae were present on 21 July in 1989, and were still present in new flowers on 29 August in 1990 (Fig. 3), but maximum infestations of 2 to 4 larvae per head occurred in late July and early August (Fig. 3). Average larval infestations per head in two fields over the season were 1.0 and 2.3 in 1989 (Fig. 3), and 1.8 and 2.4 in 1990 (Table I and Fig. 3). Generally, the mean number of larvae per new flower head decreased as the season progressed because of ageing and declining adult populations.

The majority of locations in Finland had <1 larva/20 heads and severe infestations were indicated as >1 larva/4 heads (Markkula and Myllymäki 1960). Hammer (1937) reported an average of 2.75 larvae/head at Haarlev, Denmark, where moths were extremely abundant, and where great damage was expected. Thus, infestations at New Liskeard compare with rare but severe infestations in northern Europe.

High populations in Europe are sporadic, whereas all the fields we sampled in the New Liskeard area were heavily infested. In 1990 we sampled red clover heads in three other areas of Ontario where the crop is grown for seed production. Larvae were common in Haldimand-Norfolk county (42.9°N) in southern Ontario and in Lanark (45.2°N) and Renfrew (45.5°N) counties in eastern Ontario, but were less numerous in these locations than in the New Liskeard area. Probably the more intensive production of red clover seed at New Liskeard contributed to the higher infestations. It is unlikely that the lower infestations outside the New Liskeard area resulted from recent spread of the pest because the insect already occurs from Ontario to Nova Scotia and in five northeastern states (Landry 1991).

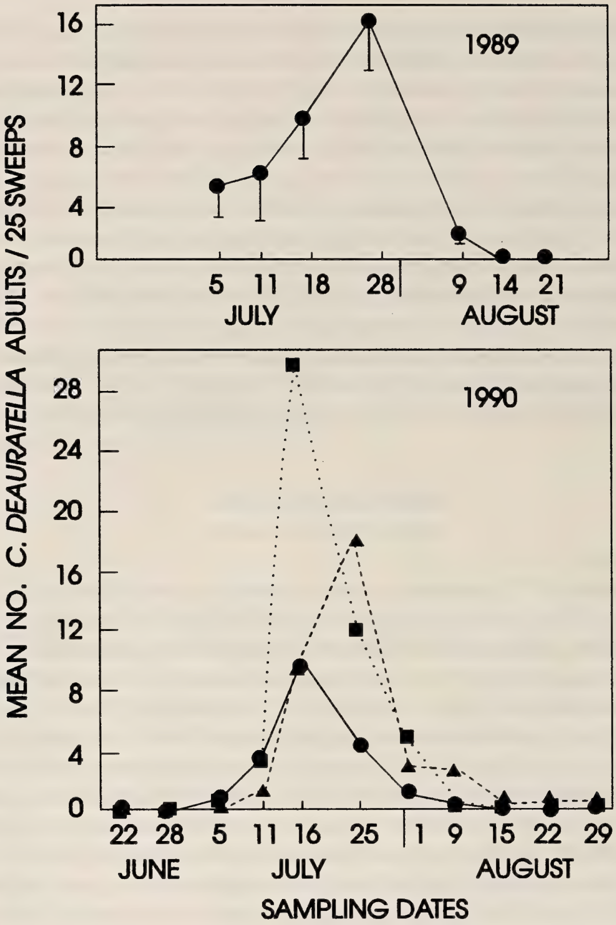

FIGURE 1. Mean number of *Coleophora deauratella* adults per 25 sweeps in fields of red clover near New Liskeard, Ontario in 1989 and 1990. Farms: 1989 ● Peters; 1990 ● Roberts, ■ Bowman, ▲ Phippen.

First instars were often found within the tip of a floret among the pistil and stamens. Second and third instars were most often found within the base of a floret (Fig. 2B). Four instars (Fig 2C) were confirmed by dissecting florets and measuring larvae. Head capsule widths of the four instars were: first 0.38±0.1 mm, second 0.76±0.2 mm, third 1.03±0.3 mm, and fourth 1.53±0.3 mm. Fourth instars construct portable cases (Fig. 2D) from the corolla of a floret, and move freely among adjacent flower heads.

Fourth instars were first obtained from sweep samples on 1 August, and increased in number until the last sampling date of 29 Aug 1990 (Fig. 4). This pattern is expected for a univoltine pest that overwinters as larvae.

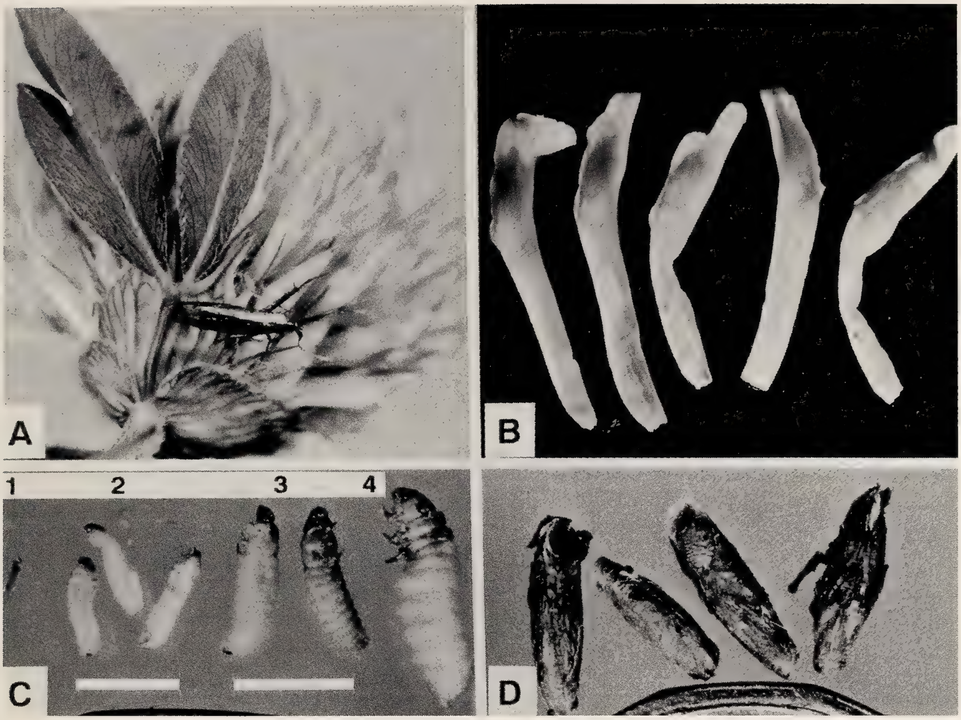

FIGURE 2. *Coleophora deauratella* (A) adult on red clover flower, (B) first instars within the base of florets, (C) the four larval instars, and (D) fourth-instar larval cases.

Floret and Seed Damage

Table I summarizes the infestation of *C. deauratella*, and the damage to flower heads collected throughout the blooming period. Because recently set heads were collected for each sample and because eggs are laid on young flowers (Markkula and Myllymäki 1960), weekly sampling represented initial infestations. Florets contained some first instars but mostly second instars. However, fourth instars were occasionally found, especially later in the season, because of movement from older seed heads.

An average initial infestation from late July to early August 1990 of 1.8 and 2.4 larvae/head damaged an average of 3.8 and 5.3 florets/head in the two fields, respectively (Table I). This damage represented an average of 3.7 and 4.6% of the potential crop. Initial infestations were highest in late July and early August, and decreased after 22 August. This trend occurred in both fields, although the population of *C. deauratella* and the damage was lower in Roberts' field than in Bowman's (Table I).

Larvae feed for 1.5 to 2 months as reported by Hammer (1937). First instars were already present in florets on 27 July 1990 when the first flowers were sampled, and fourth instars were not present until over 4 weeks later in Aug 1990. However, fourth instars feed on flower heads to complete their development before moving to the soil surface to overwinter. Hammer (1937) reported that large larvae destroyed 2 to 3 florets/day. A conservative estimate of total damage

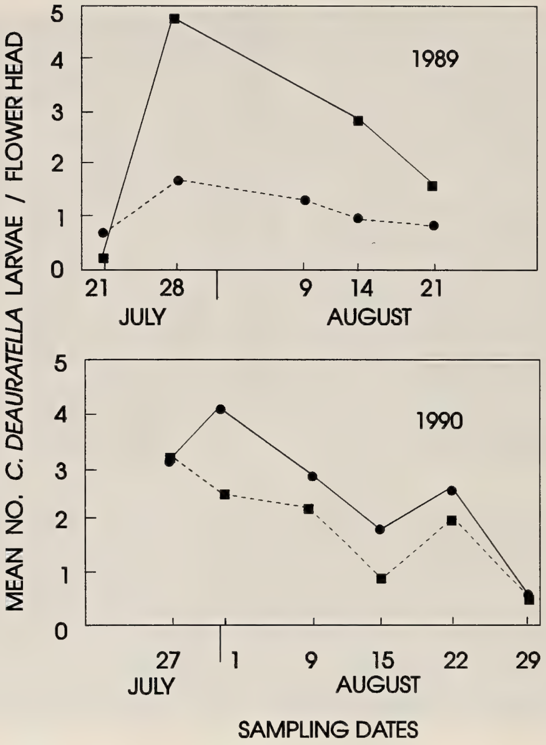

FIGURE 3. Mean number of *Coleophora deauratella* larvae per flower head in red clover from fields near New Liskeard, Ontario. Farms: 1989 ● Laframboise and ■ Peters; 1990 ● Bowman and ■ Roberts.

based on larvae destroying an average of 1 floret/day for 6 weeks would translate the New Liskeard infestations of about 2 larvae/head of 105 florets into an 80% crop loss. In other experiments, Alex Skepasts of the New Liskeard College of Agricultural Technology (unpublished data) found average seed yields in infested fields ranged from 20.1 to 54.1 kg/ha in 1989 and 1990. These yields suggest that an 80% loss occurred.

Larvae can feed on mature seed, and they often leave only the seed coat (Markkula and Myllymäki 1960). Mature seed collected at harvest from the Phippen farm in 1990 had 6.1±2.4 SE % damaged seeds. This percentage is a measure of those seeds that matured and which were only partially damaged by feeding late in the season. This percentage greatly underestimated damage because it does not include the number of flowers and seeds that were completely destroyed during the season. However, this underestimated damage is the only damage seen by growers other than reduced seed yields which can be caused by other factors including seed chalcids, plant bugs and poor pollination.

Biological Control

Because populations were low in New Zealand, sweeping was the most efficient way to collect *Coleophora* larvae from white clover, but only 39% emerged (Table II, shipment 1). The

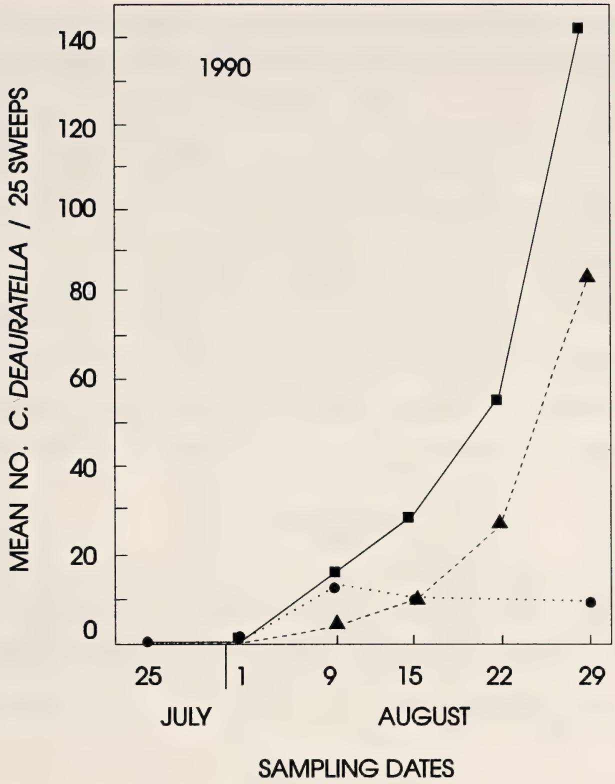

FIGURE 4. Mean number of fourth-instar *Coleophora deauratella* per 25 sweeps in fields of red clover near New Liskeard, Ontario in 1990. Farms: ● Roberts, ■ Bowman, ▲ Phippen.

remaining cases contained dead larvae, and also larvae that failed to pupate because of problems initiating and breaking larval diapause as discussed by Zwölfer (1961). The remaining three shipments were collected as mature cases from samples of leaf litter to ensure that larval development was complete. Although collecting was more time consuming, the hosts were in diapause. The second shipment (Table II) was collected in New Zealand fall, exposed from 22 May to 10 July to fluctuating cold temperatures at Sumner Forest, New Zealand, and shipped the same year for emergence in August in Ontario. Although 75-year mean temperatures at Hamner Forest were 7.3°C in May and 4.5°C in June, temperatures were inadequate to break diapause in all hosts, because emergence was poor and further emergence occurred the following July after another year of storage at 5°C. The remaining two shipments were spring collected and shipped from New Zealand, and then stored at 8°C for 6 to 8 months to synchronize emergence with host abundance in Ontario. Poor emergence under these conditions resulted from larval death in cases that were not fully sealed. In total, only 268 *N. formosa* emerged in quarantine.

Release consisted of 176 adult *N. formosa* and 35 *C. deauratella* that were exposed to *N. formosa* as second instars in quarantine. Specimens determined by C. Hansson and J. Heraty as

TABLE I. Mean numbers of florets per newly set red clover head, and larvae (*Coleophora deauratella*) and damage over the flowering period on two farms near New Liskeard, Ontario, 1990.

Farm	Date	Mean[a] number of florets/head				Initial loss (%)
		Total (±SE)	With a larva	Damaged no larva	Total damaged	
Bowman	27 July	106.2±22.0	3.0	2.1	5.1	4.8
	1 Aug	114.3±21.4	4.0	2.9	6.9	6.0
	9 Aug	115.8±23.8	2.7	1.5	4.2	3.6
	15 Aug	105.9±22.7	1.7	1.5	3.2	3.0
	22 Aug	119.6±28.0	2.4	7.7	10.1	8.4
	29 Aug	119.7±24.6	0.4	1.6	2.0	1.7
	Mean	113.6	2.4	2.9	5.3	4.6
Roberts	27 July[b]	106.2±24.6	3.2	2.5	5.7	5.4
	1 Aug[b]	98.2±23.6	2.4	2.1	4.5	4.6
	9 Aug[b]	105.9±18.8	2.1	1.6	3.7	3.5
	15 Aug	102.7±19.7	0.8	1.4	2.2	2.1
	22 Aug	108.6±28.1	1.8	3.2	5.0	4.6
	29 Aug[b]	89.8±20.2	0.3	1.5	1.8	2.0
	Mean	101.9	1.8	2.1	3.8	3.7

[a] 4 samples of 10 heads dissected per date

[b] N<40 because of missing samples

TABLE II. Collection of *Coleophora* spp. from white clover at Tai Tapu, South Island, New Zealand, and emergence of hosts and *Neochrysocharis formosa* at Guelph, Ontario.

Shipment	Collection		Shipped	N	Emerged		Released
	Type	Date			Hosts	*N. formosa* #/hosts[a]	
1	Summer/Sweeping	Jan 1991	24/7/92	419	157	68/6	none
2	Fall/Leaf Litter	May 1993	13/7/93	286	18	2/1	2
3	Spring/Leaf Litter	Sept 1993	1/10/93	250	20	69/6	67
4	Spring/Leaf Litter	Sept 1994	22/12/94	310	28	129/13	107

[a] Total parasitoids emerged/total number of hosts. In total, 268 parasitoids emerged from 26 hosts.

Neochrysocharis formosa (Westwood) were deposited in the Canadian National Collection under voucher number 196. Hansson (1990) states that, "The type material of *N. trifolii* deviates from typical *formosa* by having weak reticulation on thoracic dorsum, forewings lack infuscate spots below stigmal vein, and the stigmal vein is short — hence the postmarginal vein is almost as long as the stigmal vein, and all tibiae are pale in *trifolii*. However, since *formosa* varies in all these characters, and *trifolii* is within the limits of this variation, I regard *trifolii* as a synonym under *formosa*." J. Heraty (pers. comm.) believes the New Zealand material is different from *N. formosa* but that the species question cannot be resolved until additional biological and morphological information is obtained.

N. formosa occurs in the Nearctic region (Hansson 1990). If Hansson is correct in regarding *N. trifolii* as a synonym under *formosa*, then the species already occurs here. Neither ourselves nor J.-F. Landry , CNC Ottawa (pers. comm.) recovered *N. formosa* from *C. deauratella* reared from larval collections although several other species of parasitoids were recovered including *Bracon pygmaeus* Provancher. Specimens were deposited in the CNC. *N. formosa* is a polyphagous species that attacks mainly leaf-mining insects, but also eggs of sawflies (Hansson 1990). There are reasons to believe that the New Zealand material (= *trifolii*) is more restricted in host range.

Mixed sexes were caged together with a red clover flower for 2 to 12 hours before release so mating was presumed to have occurred. Red clover was still in bloom, and *C. deauratella* was numerous at both sites when releases were made. A follow-up is needed in 1997 to determine whether or not establishment occurred.

Acknowledgment

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SUIVI, POUR LES ANNÉES 1994 ET 1995, DES ALTISES DE L'EUPHORBE (COLEOPTERA: CHRYSOMELIDAE: *APHTHONA* SPP.) RELÂCHÉES À MARSHALL BAY (ONTARIO) CONTRE L'EUPHORBE (*EUPHORBIA ESULA* L.)

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Abstract *Proc. ent. Soc. Ont.* 127: 125-126

The introduced population of *Aphthona nigriscutis* Foudras increased significantly in 1994 and 1995, but not enough to damage the host-plant. The unexpected capture of *Aphthona flava* Guillebeau, a yellow species superficially similar to the previous one, demonstrates that specimens had evidently been misidentified in the original shipment of flea-beetles.

Résumé *Proc. ent. Soc. Ont.* 127: 125-126

La population introduite d'*Aphthona nigriscutis* Foudras s'est accrue de façon significative en 1994 et 1995, mais pas assez pour infliger des dommages à la plante-hôte. La capture imprévue d'*Aphthona flava*, une espèce jaunâtre semblable superficiellement à la précédente, démontre que certains individus ont été mal identifiés lors de l'envoi originel des altises.

Depuis l'introduction d'*Aphthona czwalinae* Weise et d'*A. nigriscutis* Foudras à Marshall Bay (près d'Arnprior, Ontario), j'ai publié un compte-rendu annuel sur leur survie dans les *Nouvelles en lutte biologique (Biocontrol News* 2:1; 3:3, 4:34, 5:22, 6:55). La disparition récente de la revue m'incite à poursuivre ici cette série d'articles.

Comme auparavant, j'ai évalué l'état des populations par 100 coups de filet effectués au hasard dans la clairière où j'avais relâché les altises et aussi dans les alentours. Le tableau I donne les résultats obtenus en 1994 et 1995.

On constate, en premier lieu, qu'*A. nigriscutis* s'est établie dans la clairière à partir de 1994 mais qu'elle n'a vraiment pris de l'expansion qu'en 1995, année où elle occupe pour la première fois tous les sites visités.

Les envois originels ne devaient "officiellement" contenir qu'*A. czwalinae* et *A. nigriscutis*. Rappelons qu'*A. czwalinae* est disparue dès la première année. *A. nigriscutis* s'est finalement établie comme je le signale ici, mais la capture de deux exemplaires d'*A. flava* Guillebeau prouve hors de tout doute qu'on a confondu des individus de cette espèce avec ceux de *nigriscutis* lors de la préparation des envois. C'était prévisible puisque les deux sont jaunâtres, de taille similaire et, de surcroît, cohabitent parfois dan les mêmes habitats. Cet incident illustre la nécessité d'améliorer les procédures de détermination des petits insectes vivants, surtout lorsqu'il s'agit d'agents utilisés en lutte biologique.

Enfin, je n'ai encore observé aucun dépérissement notable des plants d'euphorbe. Les populations d'*Aphthona* devront donc atteindre un niveau de développement beaucoup plus élevé pour être en mesure d'infliger des dommages significatifs à cette mauvaise herbe.

TABLEAU I. Résultats de l'échantillonnage d'*Aphthona nigriscutis* et d'*A. flava* sur le site d'introduction et ses abords.

Emplacement	*nigriscutis*		*flava*	
	1994	1995	1994	1995
clairière, côté ouest	99	273	0	0
clairière, côté est	81	141	0	0
300 m au sud de la clairière	0	15	1	0
200 m au nord de la clarière	0	11	0	1

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EXPANSION DE L'AIRE DE RÉPARTITION DE *CHRYSOLINA HYPERICI* (FORSTER) DEPUIS SON INTRODUCTION EN ONTARIO (COLEOPTERA: CHRYSOMELIDAE)

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Résumé *Proc. ent. Soc. Ont.* 127: 127-130

L'auteur signale les premières captures de *Chrysolina hyperici* dans trois localités du Québec situées sur la rive nord de la rivière des Outaouais. Cette Chrysomèle a progressé de 145 km vers le nord-est, à une vitesse moyenne de 6 km par année, depuis son introduction à Belleville (Ontario), en 1969, pour la lutte biologique contre le millepertuis (*Hypericum perforatum* L.)

Abstract *Proc. ent. Soc. Ont.* 127: 127-130

Captures of *Chrysolina hyperici* are reported for the first time from three localities on the north shore of the Ottawa River, in Québec. This leaf beetle moved 145 km north-eastwards, at an average speed of 6 km per year, since its introduction in Belleville (Ontario), in 1969, for the biocontrol of St. John's-wort.

Mots-clés *Chrysolina*, *hyperici*, répartition géographique, lutte biologique, expansion, vitesse, *Hypericum perforatum*.

Introduction

Chez les insectes, l'expansion de l'aire de répartition n'est mesurable, en pratique, que pour quelques espèces introduites dont on connaît le lieu et la date d'introduction. C'est le cas de la *Chrysomèle du millepertuis (Chrysolina hyperici* (Forster)) (Fig. 1) introduite en Californie en 1944 pour combattre le millepertuis (*Hypericum perforatum* L.) (Debach and Rosen 1991). Les premiers arrivages se multiplièrent tellement bien qu'on put en exporter en Colombie-Britannique dès 1955. C'est de ce stock que proviennent tous les lâchers effectués à Belleville dans le sud de l'Ontario en 1969-1970, au Nouveau-Brunswick en 1971 et 1975 et en Nouvelle-Écosse en 1969 (Harris and Maw 1984).

La présente contribution relate la progression de la *Chrysomèle du millepertuis* depuis son introduction en Ontario.

Matériel et Méthodes

J'ai récolté les premiers exemplaires de la *Chrysomèle du millepertuis* dans une sablière

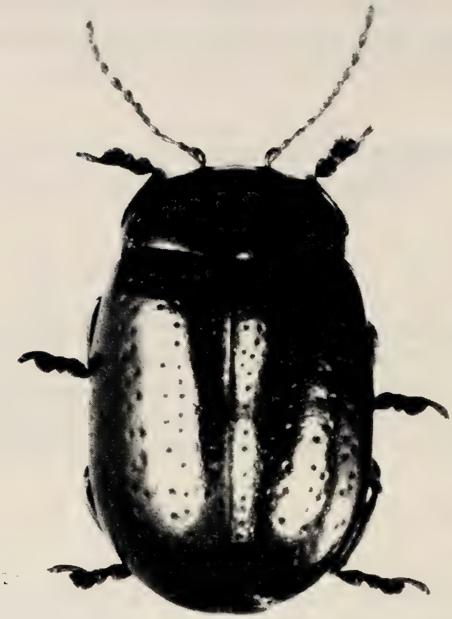

FIGURE 1. La *Chrysomèle du millepertuis*, *Chrysolina hyperici*, vue dorsale.

abandonnée de Quyon (Pontiac, Québec). Suite à cette découverte, j'ai fauché les massifs de millepertuis dans les fossés, les terrains vagues et sous les lignes électriques des localités avoisinantes.

Résultats

Le Tableau I donne les localités visitées, les dates de capture et le nombre d'exemplaires obtenus. Il ressort de ces données que la *Chrysomèle du millepertuis* a progressé vers le nord-est sur un étroit corridor puisque les captures sont toutes comprises entre Aylmer et Norway Bay.

1993 représente certainement l'année de l'arrivée de la *Chrysomèle du millepertuis* sur la rive nord de l'Outaouais puisque je ne l'ai jamais rencontrée lors de visites régulières des mêmes localités et des mêmes habitats au cours des trois années précédentes. La distance à vol d'oiseau, entre Belleville (le site de lâcher d'origine) en Ontario et Quyon sur la rive nord de la rivière des Outaouais s'établit à environ 145 km. Il s'est écoulé 24 années, soit de 1969 à 1993, avant que la *Chrysomèle du millepertuis* n'atteigne cette localité.

TABLEAU I. Résultat des récoltes de *Chrysolina hyperici* dans 8 localités de l'Outaouais (Québec), le long des routes, le bord des fossés et dans des terrains vagues.

Localité	Date	Nombre
Quyon	25.VI.93	14
Campbell's Bay	26.VI.93	0
Fort-Coulonge	26.VI.93	0
Shawville	26.VI.93	0
Aylmer	2,4.VII.93	19
Norway Bay	9.VII.93	7
Portage-du-Fort	9.VII.93	0
Hull	8.VII.93	0

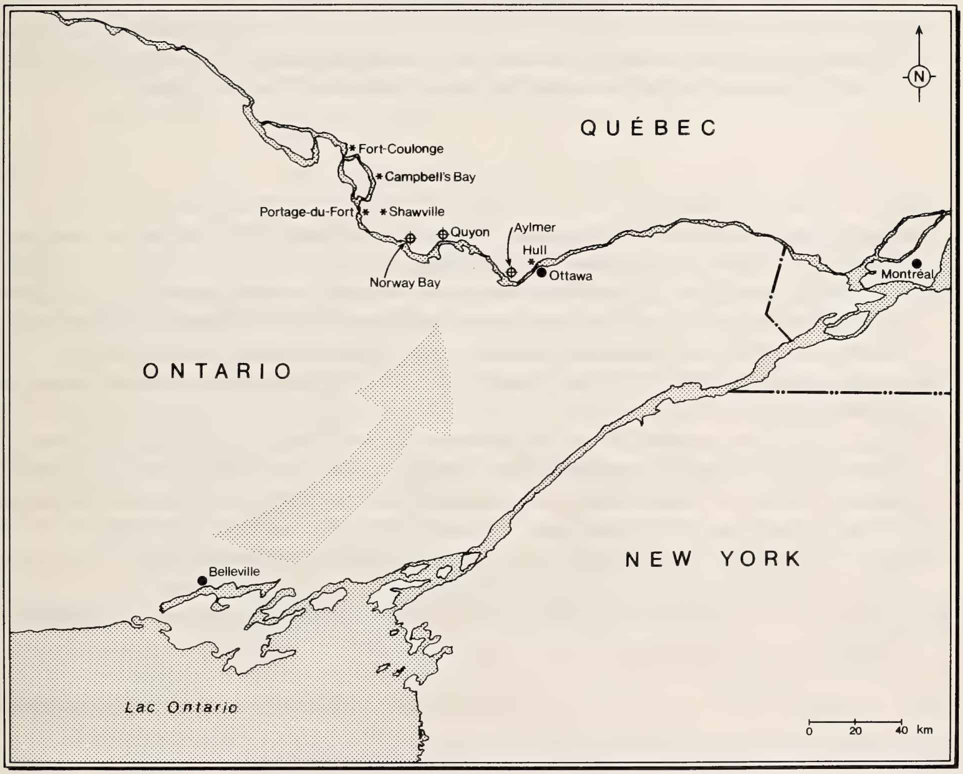

FIGURE 2. Trajectoire d'expansion (flèche) déduite à partir du lieu de lâcher d'origine, à Belleville (Ontario) et des premières récoltes de la *Chrysomèle du millepertuis*, dans plusieurs localités du Québec, au nord de la rivière des Outaouais.

Discussion

La vitesse d'expansion du *Doryphore de la pomme de terre* [*Leptinotarsa decemlineata* (Say)] représente un cas spectaculaire d'infestation incontrôlée. Entre 1861, l'année des premières dévastations et 1874, l'année où il atteint la côte atlantique, le *Doryphore* a progressé à une vitesse moyenne de 140 km par année et envahi plus de 4 millions de km^2 (Tower 1906, Trouvelot 1931). Le *Criocère des céréales*, *Oulema melanopus* (Linné), aurait pu être tout aussi dévastateur, mais des programmes vigoureux de lutte ont considérablement ralenti son expansion (Haynes and Gage 1981). Le *Criocère du lis* [*Lilioceris lilii* (Scopoli)], constitue un bel exemple de dispersion en "saut de puce" attribuable à l'activité humaine. J'ai déjà signalé (LeSage 1983) que le commerce accélérerait son expansion, prédiction confirmée par l'apparition soudaine de ce criocère à Toronto (Ontario), Wellington (Nouvelle-Écosse) et Boston (Massachusetts) quelques années plus tard (LeSage 1992).

La *Chrysomèle du millepertuis*, par contre, s'est établie progressivement, sans explosion démographique comme chez le *Doryphore*, sans être tenu en échec comme le *Criocère des céréales*, ou sans aide comme cela se produit actuellement pour le *Criocère du lis* (Fig. 2). Il faut néanmoins reconnaître que les routes et les corridors de transport des lignes électriques favorisent indirectement son expansion en fournissant un habitat favorable à la plante-hôte.

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EVIDENCE FOR THE RECENT NORTHWARD SPREAD OF *ENALLAGMA CIVILE* (ZYGOPTERA: COENAGRIONIDAE) IN SOUTHERN ONTARIO

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Abstract

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Prior to 1959 *Enallagma civile* was known in Ontario only from the Carolinian biogeographic zone in the Lake Erie—eastern Lake Ontario region. By 1996 it was known from areas at least 200 km north of the Carolinian zone boundary. Based on (1) the probable reliability of its earlier Carolinian limit, (2) the unlikelihood of it having been overlooked in regions further north where it is now widespread and abundant, and (3) its discovery at DeGrassi Point in 1959 after 50 years of intensive observation and collecting of Odonata in that area, the new distribution records are interpreted as a recent expansion of range. This expansion is believed to be due to climatic warming with increasingly extensive new habitat playing a secondary role.

Changes in the Canadian insect fauna involving native, non-pest species are poorly documented (Turnbull 1979). Satisfactory evidence for a recent northward spread of native insects in Ontario in response to climatic warming includes a few species of grasshoppers (Walker 1957), two species of Noctuid moths (Lafontaine 1996) and the damselfly, *Enallagma basidens* Calvert (Cannings 1989; Donnelly 1992). Recent observations suggested that another damselfly, *Enallagma civile* (Hagen), may also be a reliable example. Long known from the prairie provinces, northwestern Ontario and the Atlantic provinces north to Nova Scotia (Walker 1953), this species has recently extended its range in the Pacific coast region (Paulson and Garrison 1977) and in Quebec (Bellebuyck 1993, Lake Massawipi and Waterville, specimens at CNC). The range of *E. civile* in southern Ontario was noted by Walker (1941, 1953) as the extreme south "where it is limited to the counties along the north shore of Lake Erie (Kent, Elgin, Haldimand, Welland) and the western part of Lake Ontario (York)". This region corresponds to the Carolinian zone of Soper (1954), a well established biogeographic limit of many plants and animals including Zygoptera (Judd 1956). Walker's statement regarding the Carolinian distribution of *E. civile* was probably accurate because he studied Zygoptera in Canada, especially in Ontario for about 50 years and was a widely acknowledged expert to whom material was sent for identification (Wiggins 1966). Walker's collections up to 1959 (ROM on pins and in paper triangles) correspond to the extreme southwestern portion of southern Ontario that he (Walker 1941, 1953) referred to (Fig. 1). More recent collections extend the range throughout much of southern Ontario including De Grassi Point (Walker in 1959 at ROM), Gull Lake, Minden (Bowen in 1961 at CNC) and at 19 eastern Ontario localities in 1996 including sites at Ottawa, South Gloucester, Kemptville, Spencerville, Trenton and Odessa (Catling collections at CNC).

In addition to the reliability of Walker's stated Carolinian distribution, three considerations suggest that this extended range is a result of recent spread rather than a consequence of the insect having been overlooked. Firstly, it seems to be too widespread now to have been easily overlooked, and it is frequent over much of the area. For example, it occurred in 18 of 41 gravel

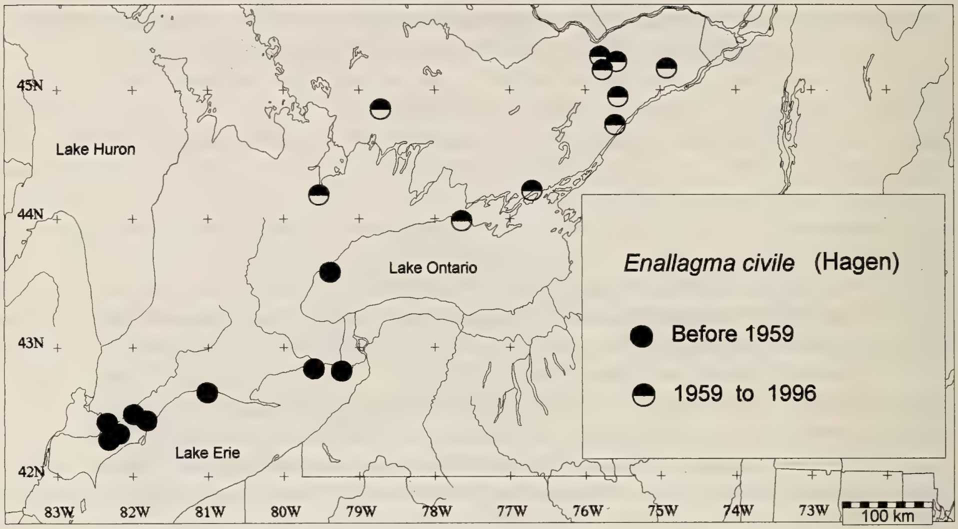

FIGURE 1. Distribution of *Enallagma civile* (Hagen) in the Carolinian zone of southern Ontario prior to 1959 (dots) and additional records after 1959 north of the Carolinian zone (half dots). All symbols are based on justifying specimens at ROM and CNC as noted in the text.

pit ponds in eastern Ontario, and proved to be one of the most abundant late summer damselflies in recently created ponds in eastern Ontario (pers. obs.). Secondly, eastern Ontario is relatively well known, the first list of Odonata around Ottawa having been published in 1908 (Walker 1908). The fact that *E. civile* was not recorded in this region until 1996, when it was found to be abundant again suggests recent expansion of range. Lastly, Walker's collection at De Grassi Point in 1959 was preceded by 50 years of intensive collecting and observing of Odonata at this site where his summer home was located (Walker 1957; Dymond 1966; Wiggins 1966). Walker's first publication on *Enallagma* appeared in 1916, and he clearly recognized representatives of the genus for almost 50 years. It is unlikely that he would have overlooked *E. civile* near De Grassi Point, if it had been there prior to 1953. The insect fauna within 10 miles of DeGrassi Point was so well known that it became the basis for one of the first authoritative evaluations of the northward movement of native southern insects in relation to climatic warming in Canada (Thomas 1957). Of course, Walker's discovery of *E. civile* at De Grassi Point in 1959 was too late to be included in his classic paper (Walker 1957). In August, 1996 it was found within 2 km of De Grassi Point within 1 hour of search, and is generally easily found within its geographic range. *E. civile* probably reached De Grassi Point in the late 1950s. Consequently, Walker's (1941, 1953) description of the Carolinian distribution in southern Ontario prior to 1953 was probably accurate at the time, and the recent extension of known range (Fig. 1) is probably a result of northward spread over the last 50 years.

E. civile takes advantage of newly created aquatic habitats (Westfall and May 1996). Although the number of man-made ponds has probably increased, man-made ponds have been extensive over the southern Ontario landscape for a long period, especially in association with railways and mills, even prior to 1900. Furthermore, newly created wetland habitats have been continuously present along lakes and rivers. Flooding by beaver may have increased recently but was also a factor in presettlement times. Consequently, the northward spread of *E. civile* is probably related to climatic warming with increasingly extensive new habitat playing a secondary role. The retreat of native boreal species is cited by several authors as support for the climatic warming hypothesis as an appropriate explanation for the northward spread of native southern species (e.g., Walker 1957; Lafontaine 1996).

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BOOK REVIEWS

The Tent Caterpillars 1995 *by* Terrence D. Fitzgerald, Cornell University Press, Ithaca. XIV + 303 pp, 134 Figures, 2 Plates, 22 Tables. $52.95 CAN

This book is the second of the *Cornell Series in Arthropod Biology*, aimed at bringing together the literature on particular insect species (or insect groups). The intent of the series is to "consider arthropods from a broad evolutionary approach". In the case of *The Tent Caterpillars*, the goal of such a synthesis from a total of 430 references is clearly attained and has resulted in a book which is indeed broad, and is at the same time highly integrated and very readable.

The book includes several requisite chapters including descriptions of the seasonal natural history of the insect, the systematics and biogeography of the genus *Malacosoma*, and two very good chapters on the general biology of the egg stage, the larvae, pupae and adults. These two chapters distinguish this book from other reviews of pest lepidoptera (Budworms (Van der Geest and Evenhuis 1991); and gypsy moth (Doane and McManus 1981)) by providing a background to general lepidopteran anatomy, physiology, and reproduction. Although the topics covered in these chapters go beyond the specifics of the tent caterpillars, the discussion does not stray far from its relevance to this group.

Where the author brings his own particular expertise to bear is in those chapters dealing with the evolution of sociality, including the importance of group feeding on herbivory, group defence from predators, and on the role of the colony and tent in providing added opportunity for thermoregulation. These chapters provide interesting insights into details of biology which might otherwise be glossed over, if not ignored, in a general discussion of a group which includes pest species. The importance of behaviour and life-history traits of tent caterpillars is well integrated into several of the chapters, sometimes to a fault. For example, in discussing reasons why forest fragmentation would prolong outbreaks of the forest tent caterpillar, the author places "increased opportunities for basking" in fragmented forests on an equal footing with the potential for altered predator-prey dynamics in those habitats.

In the chapter on population dynamics, although the mechanisms thought to affect tent caterpillar dynamics are broadly covered, there is little attempt to sort through these in order to understand the underlying issues. For example, the results of experimental work on relative importance of site effects and source population effects on tent caterpillar performance by Judy Myers is described but the significance of the results in the broad questions of population dynamics are not discussed at all.

Many papers on tent caterpillars have been published since 1993 (the year up to which papers are included in this book), and there are many researchers across Canada and the US actively working on members of this group. The increasing importance of hardwood forests such as boreal mixed wood and aspen forests will make tent caterpillars of greater and greater research interest in the near future. *The Tent Caterpillars* is therefore a very timely book, and its broad approach and synthesis makes it a very useful and interesting book grounded in a very active area of research.

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Forest Insect Pests in Canada 1995 *Edited* by J. Armstrong and W.G.H. Ives. Canadian Forest Service, Science and Sustainable Development Directorate, Ottawa, Canada. x + 732 pp. $69.95 CAN

In the worlds of Hollywood and literature, the word "sequel" often takes on and deserves a pejorative meaning, as an ambitious yet frequently disappointing follow-up to a popular and successful work. According to the Forward and Introduction, the present volume was originally intended as a sequel to *Aerial Control of Forest Insects in Canada*, which was edited by M.L. Prebble and published in 1975. Happily, the present volume is not a sequel *à la* Hollywood to Prebble (1975), which considered primarily the application of chemical pesticides from aircraft. Instead, *Forest Insect Pests in Canada* goes well beyond its predecessor in scope and ambition, offering a comprehensive view of forest pest problems and pest control issues in Canada. The ninety-three authors of its seventy chapters encompass a large part of the forest entomology community in Canada, and the volume reviews their collective knowledge of forest insects and insights into methods for managing them. A recurring theme, particularly in the introductory and summary chapters, is the current lack of chemical control options for many serious pests given the present public climate of disapproval of their use.

The volume is divided into four major parts: the biology, ecology, and regional population dynamics of forest pest insects; tools and tactics for managing pest problems; consequences of chemical control for the forest environment and nontarget communities; and summaries of regional control programmes. Part I actually consists of three undesignated sections. Chapters 1 through 6 summarize outbreak history of major pest species by region during the 1970s and 1980s. As someone who analyses time series and spatial distributions, I was pleased to see the wealth of tables containing time series and several series of outbreak maps in these chapters. Chapters 7–20 review insects of natural forests. For the most part these chapters summarize the biology, outbreak history, and control strategy for a single species or a guild of species. Spruce budworm is covered in three specialized papers on population dynamics and control introduced by an concise history of spruce budworm research by C.J. Sanders. Chapters 21–33 treat pests of plantations and managed stands. This section is introduced by an insightful essay by D.G. Embree on the philosophy, risks, and realities of controlling pests in such stands. Chapters here generally provide short but thorough summaries of biology, ecology, and control options. A notable exception to brevity is Chapter 24, which offers a comprehensive, 40-page review of the biology, systematics, ecology, physiology, and control options for diprionid sawflies. Overall, real highlights of Chapters 7 through 33 for me were the wealth of excellent color photographs illustrating many insect species and the damage they inflict.

Part II reviews recent progress in pest management technology and can be divided into two major sections. The first covers the spectrum of tools available for pest management, whereas the second treats more specialized topics related to chemical control. The first section starts with four chapters on insect pathogens, including *Bacillus thuringiensis*, viruses, fungi, and protozoa and nematodes. The chapters review historical development of these organisms for pest control and consider their potential uses and shortcomings. Three chapters cover the major classes of chemical pesticides for use against forest pests, including neurotoxins, growth regulators, and antifeedants. Another trio of chapters considers biological control along its three strategic divisions: classical biological control, augmentation and inundative releases, and conservation of naturally-occurring species. Rounding out the first section are detailed chapters on pheromones and semiochemicals and their applications. The second section provides much of the sequel to Prebble (1975). Its ten chapters cover pesticide formulation, design of efficacy trials, several technical issues related specifically to aerial application, and the latest developments in equipment for ground and aerial application. Overall, the chapters of Part II are comprehensively written, including historical and philosophical considerations as well as reviews of the state of the art.

Part III considers effects of pesticides in the forest environment beyond intended effects on a target pest. In the years since publication of Prebble (1975), there has been increased attention to monitoring and assessing these side effects. After a brief introduction by P.D. Kingsbury, two chapters consider the fate of insecticides in forest environments and the process of monitoring pesticide residues. The remaining four chapters review findings for four nontarget systems: terrestrial invertebrates, pollination, aquatic systems, and terrestrial vertebrates. An important aspect of several chapters is that they summarize succinctly the results of many studies that are either unpublished or published in relatively unavailable technical reports.

Part IV chronicles operational control programmes province-by-province from the mid 1970s to 1990. This period was one of great activity and transition in Canadian forest pest management, with major outbreaks of spruce budworm and other species in the east as well as the encroachment of gypsy moth. Some provinces were just learning to mount large-scale programmes, while others perfected them using the new technology. The period also saw an increase in public concerns over side effects of the programmes. The eight chapters provide interesting insights into adaptation of the programmes to meet often conflicting needs and concerns during this volatile period.

The book ends with a perceptive chapter on “Strategies for the future” by J.R. Carrow. He presages a near future in which economic needs require more intensive timber production on less land, which in turn requires greater protection from pests. At odds with these needs is the public pressure to ban use of virtually all chemical pesticides with few acceptable alternatives as yet commercially available. The challenges for future pest managers are clearly daunting, but Carrow remains hopeful.

Given the almost encyclopedic scope of this volume, it is likely to be a useful reference for students, researchers, and policy makers. My only serious criticism in this context is that it does not have an index, which would greatly facilitate access to the information in its 700+ pages. This shortcoming notwithstanding, *Forest Insect Pests in Canada* provides a gold mine of information on pest problems, pest control technology, and the complex of environmental, social, and political issues surrounding forest pest management. It will be a valuable addition to the shelves of forest entomologists both inside and outside Canada.

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1996 ANNUAL MEETING

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Note: Please provide figures to fit page sizes of the ***Proceedings****.*

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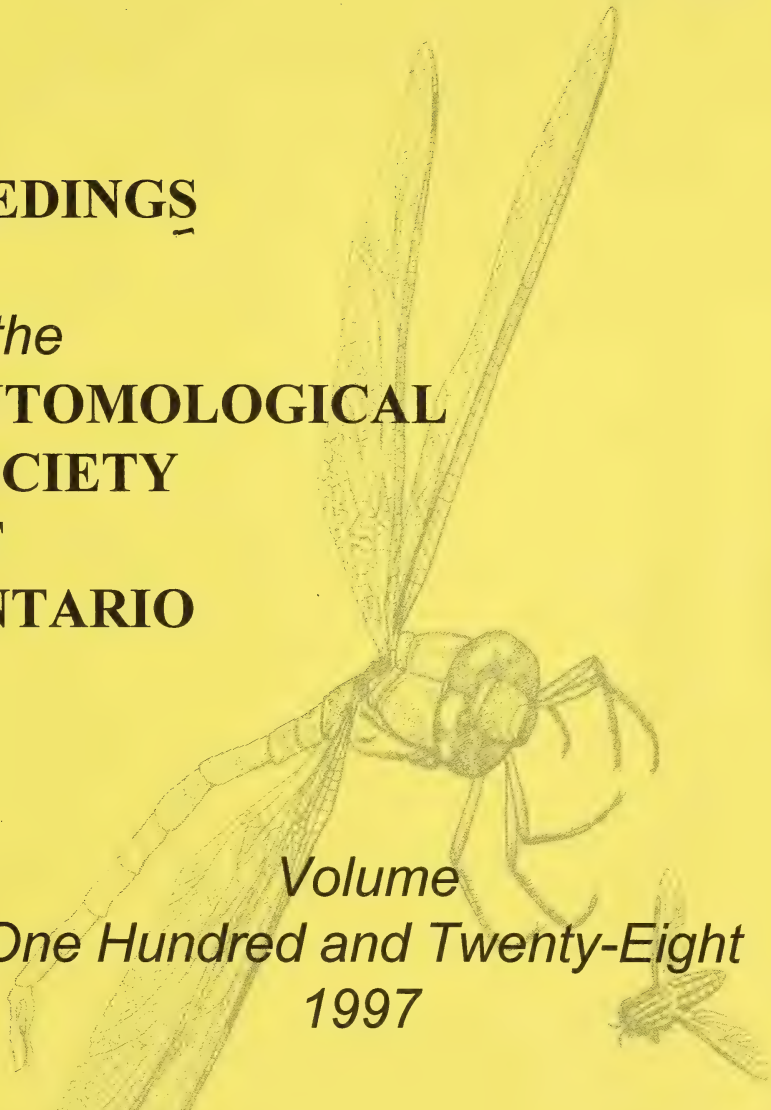

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Cover illustration: *Aeshna* sp. attacking *Chrysops* sp. Drawn by Martin Damus.

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of the

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Volume 128 ***1997***

From the Editor,

'May you live in interesting times' is supposed to be an ancient Chinese curse. I have never been able to authenticate this claim, nor do I know how much this curse may have suffered with translation into English. I must say that considering 'interesting times' something you would wish on your enemies rather than on your friends has always baffled me. However, lately I have been faced with so many interesting, but also challenging, and even distressing changes in the world, that I am beginning to develop a sympathy for the old sage who made up the curse.

In editing the Proceedings, I constantly struggle with the rapidly changing technology of information dissemination. I have barely gotten used to receiving and sending manuscripts on diskettes, and now I am flipping them back and forth on e-mail, and receiving exquisite electron micrographs on CD-ROM. Although irritating at times, minor changes like these keep the job exciting and do make life easier. All this rapid technological change, however, reminds me of a very difficult decision the Society has to make soon: how and when we will switch from an on-paper to an at least partly electronic journal. But it is not the wave of ever changing technology that makes me desire less interesting times. What concerns me, much more, are some basic changes I perceive in the way the science of entomology is practised. Science, of course, thrives on change, so it is not change *per se* that is problematic. It is the nature of the change we currently experience, and the forces that drive this change that I see as a threat to our discipline.

The kinds of changes that entomology needs are science driven changes resulting from the maturation of biology as a whole. Such a development would, undoubtedly, also serve the long term applied interests of the agriculture and forestry industries best. Instead, we are experiencing government driven changes, implicitly and perniciously imposed by various government agencies, granting bodies and industry. What is happening is that governments, under political pressure from an impatient industry, want quick, short-term solutions to currently perceived problems. Whether a situation is seen as a problem or not depends on economic and political considerations only, and the solutions are also expected to be immediately visible in terms of those disciplines.

Recently, I became an integral player in this misguided approach to solving entomological management problems. A colleague and I proposed a research project aimed at redefining a component of IPM on apple in terms of ecological equilibrium theory. We wanted to present the orchard as an ecosystem, apply some hard meta-population theory to the system, gather the necessary data on the complex interactions between certain pests and relevant beneficials and neutrals (i.e. those organisms that are not usually considered of direct economic importance). We wanted to model this system, and use the model to guide us in the design of management strategies using predator release in combination with low level use of appropriate pesticides, maintaining a complex, stable, species rich system. Perhaps our proposal was too ambitious, and unrealistic, in which case it should have been rejected. Instead, it was funded, but with the rider that we work only with pests and beneficials. In other words, the entire aim of the project had to be re-focussed on solving, with a trial-and-error approach, a short-term problem. This is only one isolated case, but talking with other entomologists, I have come to recognize this crisis management approach of government agencies as a dominant philosophy. I deplore it. I believe it will serve neither entomology, nor the agricultural and forestry industries well, in the long run.

However, I am glad to see that in this year's volume we have some very fine papers that treat entomology as a true science, as well as some papers that focus on specific applied problems. This gives me confidence that entomology will be saved by entomologists, who insist on practising their discipline the way they see fit. I congratulate the authors/researchers on their fine work, and I wish our members/readers some pleasant hours with this latest volume of our Proceedings.

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DRAGONFLIES AND DAMSELFLIES (ODONATA) OF BOSANQUET (NORTH LAMBTON COUNTY, ONTARIO)

JEFF SKEVINGTON[1] and IAN CARMICHAEL[2]

Abstract

Proc. ent. Soc. Ont. 128: 3-12

The odonate fauna of Bosanquet (North Lambton County, Ontario) is surveyed. Sixty-two species of Odonata are recorded for Bosanquet, bringing the Lambton County odonate total to 66 species. Thirty-five species are added as new to Lambton County. *Enallagma traviatum* is new to Canada and the record of *Enallagma basidens* signifies that this species is continuing to expand its range northward. *Pachydiplax longipennis* is discovered on the Lake Huron shoreline for the first time, away from its regular haunts along Lakes Erie and Ontario. *Libellula quadrimaculata* and *Nannothemis bella* were recorded in Lambton County by Walker and Corbet (1973) but were not discovered in our study. They are presumed to be extirpated.

Introduction

Lambton County is a large (299,645 ha), elongate county covering 91 km in latitude and 66 km in width (Fig. 1). Both its size and its location on the southeast shore of Lake Huron within the Carolinian forest region guarantee that it supports a large component of Ontario's biota. The present paper focuses on the Odonata of the town of Bosanquet (formerly township), a small (30,596 ha), but rich region at the northernmost end of the county (Fig. 1). Data for this project come from a survey encompassing a significant proportion of the insects found in Bosanquet. Lambton Wildlife Incorporated (LWI), a not-for-profit Sarnia-based naturalists' club, is coordinating this survey and is maintaining the list of over 2,000 species identified during this project. The list will be available in 1998 (for copies write to: Lambton Wildlife Incorporated, P.O. Box 681, Sarnia, ON N7T 7J7).

The LWI properties are representative of habitats found throughout the lakeshore area and are part of an extensive corridor of natural habitat that runs from Grand Bend to Kettle Point (24 km x 2 km) (Fig. 1). Sampling the LWI properties thus effectively samples this entire corridor. The only other significant natural land holdings in Bosanquet follow the Ausable River from near Arkona to northeast of Thedford. Most of the remaining area is farmland. The combination of a general lack of natural areas in this region and the significance of the remaining areas attracted our attention to this area. The coastal corridor of habitat retains the best examples of oak savanna and red cedar savanna in Ontario. Additionally, there are extensive areas of protected mesic forest and several high quality wetlands.

Fortunately some far-sighted groups protected parts of these areas, although the rolling dunal topography may have as much to do with its historical preservation as anything. Bosanquet formerly supported a tremendous network of wetlands. Three large, shallow inland lakes were found adjacent to the natural area being surveyed. Before being drained, Lakes Smith, George and Burwell would have supported a huge odonate fauna. Now they support a thriving vegetable industry. It would be

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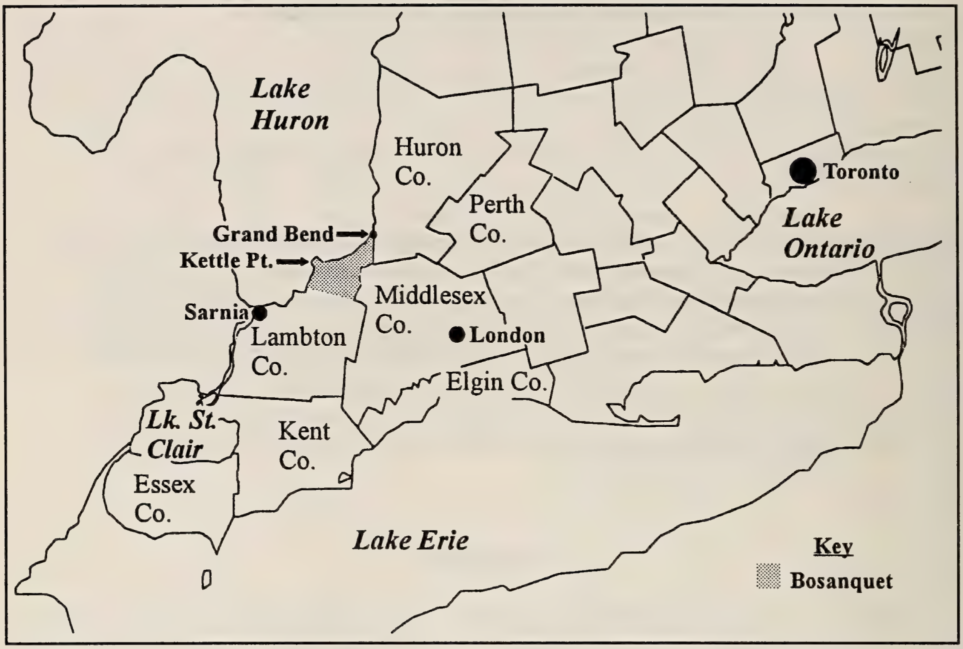

FIGURE 1. Location of study area in southwestern Ontario.

extremely useful to know what species were lost entirely with the draining of these lands, but very few data exist on the historical insect fauna of the area. This current study provides a baseline of such data for future resource managers and scientists.

Part of the coastal corridor of existing natural habitat has been granted long term protection; however, much of this protected land is under intense human pressure (for example Pinery Provincial Park squeezes over 300,000 visitors per year onto 2,428 ha). Private land holdings are quickly being purchased and developed (for example a new subdivision across from Pinery consumed approximately 32 hectares of oak savanna in 1994). Kettle Point and the former Ipperwash Army Base hold a big part of this area's natural heritage but their future is uncertain.

On a more positive note, in Port Franks, L-lake and a small but very significant unnamed lake SE of L-lake (hereafter called Pitcher Plant Pond) are protected as part of an Area of Natural and Scientific Interest (ANSI). These areas are owned by the Ausable Bayfield Conservation Authority and the Nature Conservancy of Canada. Property maintenance and access to the Nature Conservancy property is managed by LWI. The habitat here is extremely varied. Lowland floodplains are dominated by biota characteristic of the Carolinian forest region but quickly give way to savannas and prairie pockets on the dunes. The wetlands are floristically diverse and support both an abundance of Carolinian region plants and typical northern species such as pitcher plant (*Saracenia purpurea* Linnaeus) and water shield (*Brassenia schreberi* Gmelin).

Ipperwash Army Base contains two similar lakes, Bio and Moon. Permission could not be obtained to sample these lakes but the fauna should be similar to that of L-lake. Different species of

Odonata exist in the permanent lagoons and temporary ponds in the slack between the dunes on the former Army Base. The periphery of this area was surveyed but additional species could be expected here.

Pinery Provincial Park contains two wetlands, a small pond in the southwest end of the park along Carolinian Trail and the Old Ausable Channel that runs the length of the park. The river likely does not reflect its original fauna since it no longer has significant flow. River flow was reduced in 1875 when most of the water was diverted out the Canada Company Cut directly to the river mouth in Port Franks (Dixon 1963). Creation of the Grand Bend harbour in 1892 eliminated the remaining flow (Dixon 1963). Thirteen kilometres of river from Grand Bend to the Canada Company Cut is now essentially a clean inland pond, with its level maintained by springs and a dam in Pinery Park. The river has thus been separated from the rest of the Ausable and from direct agricultural run-off for 105 years. Pollution is restricted to the indirect addition of residential and campground waste. The odonate fauna is correspondingly rich.

Several surveys of Odonata have been carried out in Ontario, the most significant of which was presented in the three volume tome, The Odonata of Canada and Alaska (Walker 1953, 1958; Walker and Corbet 1973). Recent local inventories have been provided for Algonquin Provincial Park (Holder 1996), Elgin County (Stewart and Carmichael 1993), Essex County (Pratt 1988) and the Waterloo area (Furtado 1973). The Natural Heritage Information Centre is currently creating a database of Ontario Odonata.

Walker (1953, 1958) and Walker and Corbet (1973) recorded 20 species of Odonata in Lambton County and inferred the presence of an additional 11 species as "general throughout southern Ontario" (for a total of 31 species). Below, we list 66 species of Odonata for Lambton, of which we found 62 species in Bosanquet between 1991-1996. Ten of the 11 species inferred by Walker are confirmed here, only *Lestes forcipatus* could not be found. Thirty-five species are added as new to Lambton County. *Enallagma traviatum* is new to Canada and *Enallagma basidens* constitutes a significant range extension. An additional seven species are considered as likely to occur in Bosanquet but have yet to be discovered. South Lambton County was not included in the scope of this project and likely holds an additional six or more species, especially in the wetlands around Sarnia and on Walpole Island, leading one to believe that Lambton supports approximately 79 species of Odonata. This is a remarkable total that rivals the Algonquin Park faunal diversity (85 species) (Holder 1996) and the Essex County diversity (82 species) (Pratt 1988) and is comparable to the Elgin County diversity (59 species recorded + 16 species given as peripheral) (Stewart and Carmichael 1993). We found this somewhat surprising given the extent of agriculture in Lambton County and the concomitant loss of wetlands.

Materials and Methods

From 30 May 1991 to 11 September 1994 Ian Carmichael, Neva Carmichael, and Jeff Skevington collected Odonata at Pinery Provincial Park. Survey work continued in 1995 and 1996 but was less intensive. This work involved hand collecting at all available habitats throughout the summer. Spring and fall were sampled less intensively. Approximately 600 hours were spent conducting survey work in Pinery.

In 1996, survey work was expanded to include areas near Port Franks which had received only cursory study in previous years. Collections were made by hand and by six malaise traps in a variety of habitats from 1 June to 30 September. Three hundred forty-three hours were spent in the field collecting by hand, primarily by the first author. No effort was made to collect quantitative data. The survey is intended solely as a baseline inventory of the insect fauna of Bosanquet.

Specimens collected in 1996 were killed by immersing them in acetone. Colour preservation was maximized by leaving the specimens in fresh acetone for 24 hours or more. Specimens were then placed in archival envelopes for permanent storage. Specimen collection before 1996 either followed these methods or pinning with their wings spread, sometimes after immersion in acetone.

Specimens were determined using the keys in Walker (1953, 1958), Walker and Corbet (1973) and Westfall and May (1996). Vouchers for all species of Odonata collected during this project (except *Aeshna verticalis* and *Tramea lateralis*) are deposited in the University of Guelph (Department of Environmental Biology, Guelph, ON N1G 2W1). A pair of *Enallagma traviatum* and one specimen of *Aeshna verticalis* are in the Royal British Columbia Museum (Victoria, BC V8V 1X4). A pair of *Enallagma traviatum* reside in the Canadian National Collection in Ottawa (Agriculture Canada, Biosystematics Research Centre, K.W. Neatby Building, Ottawa, ON K1A 0C6). The records of *Tramea lateralis* are supported only by sight records, and *Pachydiplax longipennis* is represented by a photograph which is on file at the University of Guelph.

Scientific and common names and the arrangement of families follow Paulson and Dunkle (1996). Common names are not used in the text but are presented to encourage the burgeoning interest in Odonata by Ontario naturalists. Species are arranged alphabetically within the families.

Results

Table I lists the species recorded during the study and those species listed for Lambton County by Walker (1953, 1958) and Walker and Corbet (1973). Numbers under each location refer to the number of specimens collected and do not necessarily reflect abundance.

Discussion

Three southeastern species were discovered outside of their normal ranges, *Enallagma basidens*, *Enallagma traviatum* and *Pachydiplax longipennis*.

Enallagma basidens was only recently added to the Canadian fauna when it was discovered in Essex County at Scudder, Pelee Island and Windsor in 1985 (Cannings 1989). It has since been found in South Lambton County along the North Sydenham River south of Wilkesport (Cannings 1989). *Enallagma basidens* has undergone a considerable range expansion in this century (Cannings 1989). It has spread from Texas as far northwest as California and Colorado and as far northeast as New York and has now been recorded in four states adjacent to Ontario (New York, Ohio, Pennsylvania and Wisconsin) (Westfall and May 1996). As described below, *E. basidens* has continued to spread north and is now found in North Lambton County at the edge of the Carolinian forest region. The second author collected one specimen of this diminutive species on the Ausable River in Pinery Provincial Park on 9 July 1991 where the lookout platform for Cedar Trail now stands. In this area the Ausable River has almost no flow and would best be described as a permanent pond with dense aquatic vegetation and a moderate amount of emergent vegetation. A pair of *E. traviatum* were collected at this same location on 24 July 1991. The first specimens of *E. traviatum* that we found were collected three kilometres downstream from this location about a month earlier (26 June 1991, Pinery Provincial Park south bridge, two pairs *in copula*). An additional two pairs were collected from a similar habitat on 5 July 1996 at L-lake, Port Franks.

Enallagma traviatum was previously unknown from Canada but was an expected addition to our fauna. Westfall and May (1996) considered it to be fairly common in the eastern United States and recorded it in all of the states adjacent to Ontario except Minnesota (Michigan, New York, Ohio, Pennsylvania, Wisconsin). It should be looked for in permanent weedy ponds and lakes elsewhere in

TABLE I. The Odonata of Lambton County, Ontario (66 confirmed species plus 1 unconfirmed species).

	KBS	PFD	PPP	IAB	NL	WAL	DET
Calopterygidae — 2 species							
Calopteryx maculata (Beauvois) (ebony jewelwing)		5	1		2	★	2,4
NL specimens from the Ausable River near Sylvan and from the Thedford area							
Hetaerina americana (Fabricius) (American rubyspot)					1	✓	4
NL specimen from Hungry Hollow							
Lestidae — 6 confirmed species + 1 unconfirmed species [in square brackets]							
Lestes disjunctus disjunctus Selys (common spreadwing)			7		3	★	2,4
NL specimens from Thedford area							
Lestes dryas Kirby (emerald spreadwing)		8				★	4
[*Lestes forcipatus* Rambur (sweetflag spreadwing)]						★	
**Lestes inaequalis* Walsh (elegant spreadwing)			10				2,4
Lestes rectangularis Say (slender spreadwing)		13	3			★	2,4
Lestes unguiculatus Hagen (lyre-tipped spreadwing)		1	2			✓	2,4
Lestes vigilax Hagen (swamp spreadwing)		2	8	1		✓	2,4
Coenagrionidae — 19 species							
**Argia apicalis* (Say) (blue-fronted dancer)			4		1		2,4
NL specimen from Thedford area							
**Argia fumipennis violacea* (Hagen) (variable dancer)		11	4				2,4
**Chromagrion conditum* (Hagen in Selys) (aurora damsel)		4					4
Coenagrion resolutum (Hagen in Selys) (taiga bluet)		6				★	4
Enallagma antennatum (Say) (rainbow bluet)		2	2			✓	2,4
Enallagma basidens Calvert (double-striped bluet)			1				1
Enallagma carunculatum Morse (tule bluet)			1			✓	2,4
**Enallagma civile* (Hagen) (familiar bluet)	5	4	1		2		2,4
NL specimens from Thedford Sewage Lagoons							
**Enallagma cyathigerum* (Charpentier) (northern bluet)			2				2,4
Enallagma ebrium (Hagen) (marsh bluet)		1				★	4
Enallagma exsulans (Hagen) (stream bluet)			1			★	2,4
**Enallagma geminatum* Kellicott (skimming bluet)		1	2				2,4
Enallagma hageni (Walsh) (Hagen's bluet)		24	13			★	2,4
**Enallagma signatum* (Hagen) (orange bluet)			2				2,4
**Enallagma traviatum westfalli* Donnelly (slender bluet)		4	6				3,4
**Enallagma vesperum* Calvert (vesper bluet)			4				2,4
**Ischnura posita* (Hagen) (fragile forktail)		2	2				2,4
Ischnura verticalis (Say) (eastern forktail)	3	21	5		1	★	2,4
Nehalennia irene (Hagen) (sedge sprite)		14				★	4
Aeshnidae — 7 species							
**Aeshna canadensis* Walker (Canada darner)		2	1				4
Aeshna constricta Say (lance-tipped darner)	5	2	3			✓	2,4
Aeshna umbrosa umbrosa Walker (shadow darner)			3			✓	2,4
**Aeshna verticalis* Hagen (green-striped darner)		1					4
**Anax junius* (Drury) (common green darner)	Ob	2	4				2,4
**Basiaeschna janata* (Say) (springtime darner)		2	4				2,4
**Boyeria vinosa* (Say) (fawn darner)		2	1				4
Gomphidae — 6 species							
**Arigomphus furcifer* (Hagen) (lilypad clubtail)			3				2,4
**Gomphurus fraternus fraternus* (Say) (midland clubtail)		1					4
**Gomphus exilis* Selys (lancet clubtail)		5	9				2,4
Gomphus graslinellus Walsh (pronghorn clubtail)			2			✓	4
Walker's (1958) record of this species is for the St. Clair River in South Lambton County							

TABLE I — continued

	KBS	PFD	PPP	IAB	NL	WAL	DET
**Gomphus spicatus* Hagen in Selys (dusky clubtail)		6	4				2,4
Stylurus notatus (Rambur) (elusive clubtail)						✓	
Walker's (1958) record of this species is for the St. Clair River. It is a species of large rivers and is not expected in North Lambton.							
Corduliidae — 3 species							
**Dorocordulia libera* (Selys) (racket-tailed emerald)		2					4
**Epitheca cynosura* (Say) (common baskettail)		6	7				2,4
**Somatochlora williamsoni* Walker (Williamson's emerald)				1			4
Libellulidae — 23 species							
Celithemis elisa (Hagen) (calico pennant)	1	2	2	1		✓	2,4
Celithemis eponina (Drury) (halloween pennant)			1			✓	2
**Erythemis simplicicollis* (Say) (eastern pondhawk)		3	3				2,4
**Leucorrhinia frigida* Hagen (frosted whiteface)				1			4
**Leucorrhinia glacialis* Hagen (crimson-ringed whiteface)					1		4
NL specimen from Sylvan Scout Camp (just outside of Lambton County in Middlesex County — expected in adjacent Lambton County)							
Leucorrhinia intacta (Hagen) (dot-tailed whiteface)		4	8			✓	2,4
**Libellula incesta* Hagen (slaty skimmer)	1	8					4
**Libellula julia* Uhler (chalk-fronted corporal)		4	4				2,4
Libellula luctuosa Burmeister (widow skimmer)	1	1	7			✓	2,4
**Libellula lydia* Drury (common whitetail)	Ob	2	6				2,4
Libellula pulchella Drury (twelve-spotted skimmer)		1	2			✓	2,4
Libellula quadrimaculata Linnaeus (four-spotted skimmer)						✓	
Nannothemis bella (Uhler) (elfin skimmer)						✓	
**Pachydiplax longipennis* (Burmeister) (blue dasher)		P					4
Pantala flavescens (Fabricius) (globe glider)			1	1	1	✓	4
NL specimen from Kettle Point. Walker and Corbet (1973) recorded this species at Point Edward in Sarnia (South Lambton).							
**Perithemis tenera* (Say) (eastern amberwing)		2	3				2,4
Sympetrum costiferum (Hagen) (saffron-winged meadowhawk)						✓	
**Sympetrum internum* Montgomery (cherry-faced meadowhawk)		2					4
**Sympetrum obtrusum* (Hagen) (white-faced meadowhawk)	1	21	2	2			2,4
Sympetrum rubicundulum (Say) (ruby meadowhawk)	8	7	2		1		2,4
NL specimen from Thedford area.							
**Sympetrum semicinctum* (Say) (band-winged meadowhawk)		7					4
Sympetrum vicinum (Hagen) (yellow-legged meadowhawk)	Ob	3	8				2,4
**Tramea lacerata* Hagen (black saddlebags)		Ob	Ob				4

Key to symbols used in Table I:

KBS	Karner Blue Sanctuary — This Port Franks property is owned by LWI. The habitat is dominated by oak savanna. Odonata collected here wandered in from nearby wetlands.
PFD	Port Franks Forested Dunes (formerly Watson Property) — Strictly, this property includes only part of L-lake and part of Mud Creek (both in the town of Port Franks). The property is owned by the Nature Conservancy of Canada and is managed by LWI. Here the area is referred to in a broader sense and includes adjacent parts of L-lake and a small lake SE of L-lake entirely on Ausable Bayfield Conservation Authority property ("Pitcher Plant Pond"). Note: PFD is recorded on insect labels as "Watson Property near L-lake".
PPP	Pinery Provincial Park.
IAB	Ipperwash Army Base — This property is of immense interest and contains many wetlands. It was only surveyed along the periphery since the property ownership is in contention (either Federal Army property or First Nations land).

NL	North Lambton County - This category absorbs incidental records from areas not included above.
WAL	Walker — This refers to records listed for Lambton County by Walker (1953, 1958) and Walker and Corbet (1973). It should not be assumed that these records are for North Lambton, but they are offered as the only previous baseline of information on the area.
DET	Determined by — This refers to the entomologist who identified the species in question. They are: (1) R.A.Cannings, (2) I. Carmichael, (3) T.W. Donnelly, (4) J.Skevington.
Ob	Observed only. No specimen collected.
P	Photographic record. Photograph deposited in University of Guelph as a voucher.
*	Indicates a new record for Lambton County.
✓	Species recorded in Lambton County by Walker (1953, 1958) or Walker and Corbet (1973).
★	Species of general occurrence, inferred by Walker (1953, 1958) or Walker and Corbet (1973) to occur in Lambton County.

southern Ontario. We found that this species was associating with emergent plants away from the shore. Collectors using a canoe or chest waders to get away from the shore may have a higher chance of discovering this species.

Pachydiplax longipennis is common in Ontario along the north shores of Lakes Erie and Ontario, but is rare away from these lakes (Walker and Corbet 1973). It has never been recorded from the Lake Huron shoreline until now.

A number of other species reflected apparent changes in abundance since Walker (1953, 1958) and Walker and Corbet (1973). *Enallagma civile* appears to be changing its distribution and abundance in Ontario. Walker (1953) suggested that this species was local and uncommon in southern Ontario, a region where it is now widespread and abundant. Stewart and Carmichael (1993) found that *E. civile* was the commonest *Enallagma* in Elgin County and we feel that it is the most abundant Lambton zygopteran in disturbed habitats. It was present in swarms around sewage lagoons at Grand Bend, Thedford and Forest. It may be the prevalence of lagoons such as these that has allowed this species to spread and dominate. Voshell and Simmons (1978) suggest that *Enallagma civile* is especially adept at colonizing temporary or newly created aquatic habitats. Catling (1996) established that *E. civile* is now one of the most abundant late summer damselflies in recently created ponds in Eastern Ontario and suggested that this species' recent expansion may be primarily related to climatic warming. Westfall and May (1996) suggest that this is now one of the most common of the Odonata in many places and is perhaps the most widespread North American damselfly.

Walker and Corbet (1973) considered *Libellula luctuosa* to be rare in Ontario at the turn of the century, but noted that it was increasing over the next 50 years. This trend seems to have continued and we feel that this is the most common large libellulid in North Lambton County. Another large libellulid has apparently followed the opposite course. *Libellula pulchella*, can no longer be considered to be "one of the commonest dragonflies in southern Ontario" (Walker and Corbet 1973). Although widespread and conspicuous, this is one of Lambton County's least common large libellulids.

Pantala flavescens is an eruptive migrant that cannot overwinter in Ontario (Walker and Corbet 1973). Somewhat surprisingly, it was present annually in low numbers at the Ipperwash Army Base from 1989 to 1995, suggesting that isolated populations may persist through the winter at some sites. This species staged an impressive invasion in 1995 and there was nowhere that we travelled in southern Ontario that we could not find this species. In North Lambton, hundreds were present at the Ipperwash Army Base and Kettle Point, mating and ovipositing in the unvegetated sandy ponds. Smaller numbers were encountered elsewhere. In 1996 the species was conspicuously absent from all sites, including the Army Base. The only *Pantala* seen in Lambton County in 1996 was a single individual of what was likely *P. hymenea* seen on 25 June in Sarnia. It could not be captured for confirmation. A single specimen of *P. flavescens* was observed on 8 August 1996 in St. Joseph, a few kilometres north of the Lambton County boundary.

Another erratic immigrant is *Tramea lacerata*. Like *Pantala*, this species cannot overwinter in Ontario (Walker and Corbet 1973), but unlike *P. flavescens* which wanders widely, *T. lacerata* is restricted to the Carolinian forest region in Ontario (Walker and Corbet 1973). In 1996, the first author observed two specimens of *T. lacerata* on 6 August at Pitcher Plant Pond, Port Franks, and one specimen on 19 September at Pinery Park. These records provide the first evidence that this species occurs along the southern shore of Lake Huron. This range extension is not surprising since North Lambton County forms the northernmost extension of the Carolinian forest region in Ontario (Theberge 1989). In addition to *T. lacerata*, five other species of Odonata were found here at or near the northern edge of their range: *Argia apicalis*, *Gomphus graslinellus*, *Hetaerina americana*, *Pachydiplax longipennis* and *Perithemis tenera*. *Hetaerina americana* has been found slightly north of the Carolinian region in Huron, Perth and Wellington Counties (Walker 1953, personal observation). *Perithemis tenera* has been found in Huron County (Walker and Corbet 1973) and *Gomphus graslinellis* may breed in the Kenora District (Walker 1958).

The most common species of Odonata in North Lambton as judged by the authors (not based on quantitative data) include (listed alphabetically): *Aeshna constricta*, *Anax junius*, *Argia fumipennis*, *Enallagma civile* (lagoons), *Enallagma hageni* (natural ponds), *Epitheca cynosura*, *Ischnura verticalis*, *Lestes rectangularis*, *Leucorrhinia intacta*, *Libellula incesta*, *Libellula julia*, *Libellula luctuosa*, *Libellula lydia*, *Sympetrum obtrusum* and *Sympetrum vicinum*. Of these, the most common damselfly is *Ischnura verticalis*. Westfall and May (1996) consider this species to be one of the most common Zygoptera in the northeastern United States and eastern Canada. The most common large dragonfly in Lambton is *Libellula luctuosa* and the most common small dragonfly is *Sympetrum vicinum*.

Four species recorded by Walker (1953, 1958) and Walker and Corbet (1973) were not found in this study. *Stylurus notatus*, a species of large bodies of water, was found along the St. Clair River (Walker 1958) and is not expected in North Lambton. *Sympetrum costiferum* is a widespread species that we likely overlooked. The best habitats for this species are the sandy interdunal lagoons at Ipperwash Army Base and the temporary sand-bottomed ponds at Kettle Point. More time spent searching these locations will almost certainly turn up this species. *Nannothemis bella* and *Libellula quadrimaculata* may be extirpated from the county. The former is dependent on sphagnum bogs in Canada and has disappeared with its habitat. It is unlikely to be found again in Lambton County. *Libellula quadrimaculata* presents more of a problem. This species is widely distributed throughout the Holarctic and was recognized by Walker and Corbet (1973) as the most common large libellulid in Canada. It is found in any still waters in marshy or boggy ground, especially in peaty waters (Walker and Corbet 1973). They are conspicuous, stray far from their emergence sites and are known to be migratory so it is unusual that they were not discovered during our study. In Algonquin Park they are listed as the second most abundant large skimmer (Holder 1996), but in Elgin County they are considered to be scarce and are known from only three sites (Stewart and Carmichael 1993). We have not noticed this species to be common anywhere in southwestern Ontario and feel that it has declined and disappeared from much of this area or is erratic in its appearance like other migratory libellulids (*Pantala* and *Tramea* for example).

Walker (1953) did not confirm that *Lestes forcipatus* occurred in Lambton County but suggested that it was found throughout southern and central Ontario. Its absence on the Algonquin Park list (Holder 1996) and its presence at only two locations in Elgin County (Stewart and Carmichael 1993) suggests that this distribution is incorrect or has changed.

Future work on the Odonata of North Lambton County should focus on the Ipperwash Army Base, Kettle Point and the Ausable River between Arkona and Thedford. Based on habitat requirements and their occurrence in peripheral areas, the following seven species of Odonata not yet discovered in Lambton are expected to be found: *Amphiagrion saucium* (Burmeister), *Argia moesta* (Hagen), *Calopteryx aequabilis* Say, *Epitheca princeps* Hagen, *Lestes congener* Hagen, *Lestes forcipatus* Rambur and *Macromia illinoiensis* Walsh. An additional six species are less likely, but are also anticipated: *Enallagma aspersum* (Hagen), *Enallagma boreale* (Selys), *Epiaeschna heros* (Fabricius), *Libellula semifasciata* Burmeister, *Ophiogomphus rupinsulensis* (Walsh) and *Sympetrum corruptum* (Hagen).

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BEHAVIOURAL RESPONSES OF THE EASTERN SUBTERRANEAN TERMITE TO FALLING TEMPERATURES (ISOPTERA: RHINOTERMITIDAE)

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Abstract

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Laboratory populations of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), were exposed to a temperature regime that dropped by five degrees Centigrade every nine days, from 20 to 0°C. Tunnelling and foraging activity was observed during the 20, 15, and 10°C temperature periods, but slowed when the temperature reached 5°C. All activity ceased at 0°C. There was no indication that *R. flavipes* aggregated within available food sources as the temperature dropped. There was also no measurable production of heat in the food sources compared to the surrounding soil. Termites moved downward in the soil as the temperatures fell from 5 to 0°C.

Introduction

The termite genus *Reticulitermes* (Isoptera: Rhinotermitidae) occurs in a broad band throughout the temperate regions of North America, Europe and Asia. It occurs farther north than any other genus of subterranean termite, though it seldom extends beyond 46°N (Harris 1970; Weesner 1970). In Ontario, *Reticulitermes flavipes* (Kollar) is not found any farther north than Kincardine, presumably due to cold temperatures and a relatively short foraging season. While there have been several studies conducted on *Reticulitermes* with regards to cold tolerance and seasonal caste fluctuations, little is known of its overwintering biology (Esenther 1969; Harris 1970; Weesner 1970; Davis and Kamble 1994; Grace 1996).

Myles and Grace (1991) suggest that in Toronto, the eastern subterranean termite, *R. flavipes*, overwinters by moving downward in the soil to seek out the residual heat provided by building foundations and sewer pipes. In Wisconsin, Esenther (1969) observed that during the winter months *R. flavipes* descended to a depth of approximately 1.5 metres, while in Ontario, Husby (1980) recorded *R. flavipes* at a depth of 95 cm. According to Grace (1996), *R. flavipes* can occasionally be found during the winter within large stumps at the soil surface.

Termites are not known to enter diapause when subjected to cold temperatures, raising the possibility that they maintain some level of activity during the winter months. Given that the population of a colony of *R. flavipes* can number in the millions (Grace 1990), the formation of large aggregations within a food source, such as a stump or log, may allow the colony to generate and retain metabolic heat, permitting them to remain active throughout the winter.

Southwick (1991) maintains that the honeybee is the only insect that remains physically active during the winter as a social group, however only a few studies have been conducted on the overwintering behaviour of other social insects, such as termites (Husby 1980; Davis and Kamble 1994) and ants (Coenen-Stab *et al.* 1980).

Numerous investigations, cited by Noirot (1970), Wood (1988), and Seeley and Heinrich (1981), have been conducted on the ability of nest-building termites to regulate nest temperatures, cooling it during the day and warming it at night. These studies, however, have usually been conducted with the large mounds of *Macrotermes*, and the nests excavated in living trees by *Coptotermes*, *Thoracotermes* and *Cephalotermes*, and have investigated temperature homeostasis relative to a diurnal cycle. In contrast, the colonies of non-nest building subterranean termites, such as *Reticulitermes*, which consist largely of a diffuse network of interconnected galleries and nursery areas scattered throughout the soil and wood, may not allow them to regulate temperature.

The objective of this experiment was to simulate the gradually decreasing soil temperature conditions from autumn to winter to determine if there is a temperature at which termites noticeably start to socially aggregate in or around their food sources to conserve metabolic heat, or in some other way adaptively respond to gradual cooling.

Materials and Methods

Termites were collected during the months of August and September, 1996, from the municipal composting site on Unwin Street, operated by the City of Toronto, in Ontario, Canada. Two holes, approximately five metres apart and one metre deep, were filled with rolls of corrugated cardboard. These were covered with soil and pieces of wood and left undisturbed for two weeks. The site was visited every two weeks and the rolls containing termites were removed to the laboratory. The rolls were unravelled over a sieve, which collected pieces of cardboard and debris, but allowed the termites and any soil to fall through to a plastic tub below. To separate the termites from the soil, the mixture of termites and soil was placed in a bin that contained a plastic tray overlaying sheets of moistened cardboard. As the soil dried over a 24 hr period, the termites crawled over the edge of the tray and into the sheets of cardboard below. The termites, which were now clean, were then removed and placed in plastic tubs containing moistened cardboard and maintained until the beginning of the experiment in October, 1996.

Twenty translucent plastic tubs, 40 cm x 28 cm x 15 cm (Tamor Plastics Corp. MA), were prepared for housing termites by filling the bottom of each with a mixture of clay loam (300 ml), brick sand (150 ml) and distilled water (125 ml). This mixture was covered with seven litres of moist, sterilized commercial grade topsoil (Custom Blend Ltd., ON), which provided a total soil depth of approximately 13 cm. Food sources consisted of a roll of corrugated cardboard, 10 cm x 8 cm, wrapped around pieces of aspen wood (total mass of wood = 6.72 g) and secured with a rubber band. Each food source was moistened with 50 ml of distilled water. Two food sources were buried vertically in each of the tubs, approximately 15 cm apart, with the top of each cardboard roll even with the surface of the soil. The bottom of each roll was approximately 3 cm above the bottom of the tub.

The termites were removed from their cultures and a mass of 24.75 g of termites, representing approximately 8, 534 individuals, was introduced into each of the replicates by gently pouring them out of a beaker over the surface of the soil. The tubs were then covered with plastic lids, which had several small holes for ventilation. Ten control replicates were maintained in the laboratory, in darkness, at ambient room temperature (*ca.* 20°C). Ten treatment replicates were removed to an environmental chamber (Conviron Controlled Environment Chamber, model GR 36) and maintained in darkness at an initial temperature of 20°C. The temperature within the chamber was dropped by five degree increments every nine days, until 0°C was reached. The 0°C condition was maintained for a period of three days to reduce the likelihood that the termites would die from exposure to the cold (Davis and Kamble 1994).

Aggregation of termites within food sources. To establish whether the termites had aggregated within one of the two food sources provided, the mass of the wood within each of the replicates was compared at the end of the experiment to determine how much wood had been consumed. This was done by removing the pieces of aspen wood at the end of the experiment, brushing them lightly with tissue paper to remove debris, drying them in an oven (Fisher Scientific, model 230-G) for 72 hours, and re-weighing them to determine any change in mass.

Generation of metabolic heat. To determine whether heat was generated by termites clustering and feeding within food resources, the temperature within each cardboard roll was recorded on the ninth day of each of the temperature regimes with a digital thermometer equipped with a 5 cm long probe (Fisher Scientific, model 15094). The probe was inserted into the centre of each food source and, for comparison, into the surrounding soil, approximately 10 cm from the food sources.

Downward movement in the soil. To determine whether termites move down the soil in response to falling temperatures, a measurement of termite density at the bottom of each of the tubs was calculated on the last day of the experiment. This was accomplished by overlaying a transparent film with a grid of 70 cells (a cell being 25 x 25 mm) across a central section of the bottom of each replicate and counting, from below, the number of termites observed within each cell.

Direct Observations. Termite activity was observed by inspecting the translucent bottoms of the tubs during each of the temperature readings. By observing whether the termites were actively engaged in tunnelling or foraging, inferences about termite health could be made without having to physically interfere with the test environment. At the end of the test, the soil was gently removed and sifted by hand as the tubs were dismantled to determine whether chambers had been constructed by the termites in the soil or aggregations had formed.

Results

Aggregation of termites within food sources. As expected, the termites consumed significantly less food under the falling temperature regime than under the control regime (average mass of wood consumed in controls: 2.42 g ± 0.2 SE; average mass of wood consumed in treatments: 0.43 g ± 0.1 SE; $P<0.0005$; $T=9.4$; $df=36$, independent samples t-test, SPSS Inc. 1995). There was no indication that termites had fed more on one food source than the other in either the treatment or control replicates (Table I).

TABLE I. Wood consumed by populations of *Reticulitermes flavipes* from two equal food sources under two different temperate regimes.

Temperature condition	Mean (g)*
Falling temperature regime	
food source 1	0.46 ± 0.14 a
food source 2	0.41 ± 0.12 a
Ambient lab temperature (control)	
food source 1	2.37 ± 0.32 a
food source 2	2.52 ± 0.20 a

* Means followed by the same letter are not significantly different. Falling temperature regime: $P=0.831$, $df=8$; ambient lab temperature regime: $P=0.607$, $df=9$, paired-samples t-test.

Generation and retention of metabolic heat. Comparison of the temperature probe data shows that no food source was warmer than the other during each temperature regime under the treatment condition. Furthermore, no food source was significantly warmer than the surrounding soil (Table II). There was no significant difference between the temperature recorded in each of the food sources in the control replicates, nor was there a significant difference between the temperature of the food

TABLE II. Mean temperatures recorded from the soil and food sources of laboratory colonies of *Reticulitermes flavipes* under different temperature regimes.

	Temperature regime (°C)*				
	20	15	10	5	0
soil	20.67 ± 0.04a	14.20 ± 0.07a	10.10 ± 0.16a	4.28 ± 0.18a	0.57 ± 0.26a
food source 1	20.56 ± 0.05a	14.26 ± 0.10a	10.02 ± 0.14a	4.14 ± 0.18a	0.22 ± 0.22a
food source 2	20.54 ± 0.24a	14.19 ± 0.08a	9.90 ± 0.14a	4.33 ± 0.20a	0.11 ± 0.16a

* Means within a column followed by the same letter are not statistically significant. Temperature regimes (df=27): 20°C, F=1.42, P=0.2582; 15°C, F=0.20, P=0.8231; 10°C, F=0.22, P=0.7997; 5°C, F=0.27, P=0.7638; 0°C, F=1.23, P=0.3076.

sources and the soil (average soil temperature: 22.42°C ± 0.1 SE; average temperature within food source 1: 22.49°C ± 0.1 SE and food source 2: 22.47°C ± 0.1 SE; P=0.8786, F=0.1308, df=14).

Direct observations. The termites in the control replicates were observed foraging for the duration of the experiment. In the treatment condition, the termites foraged during the 20, 15, and 10°C temperature regimes. At 5°C the termites foraged very slowly and at 0°C all foraging ceased and the termites were motionless. When the tubs were brought into warmer air at the end of the experiment, termite activity resumed within one hour, indicating they had not died from exposure.

Downward movement in the soil. Visual assessment indicated that by the end of the experiment, significantly more termites had moved into the lower-most galleries of the tubs under the treatment condition. This was supported by the counts of termites in the grid area at the bottom of the tubs. The average number of termites per grid cell in the treatment replicates was 11.35 ± 0.53 SE, *versus* 1.47 ± 0.16 SE in the controls ($P<0.0005$; T=18.01; independent samples t-test, SPSS 1995).

Discussion

The overwintering biology of the eastern subterranean termite, *Reticulitermes flavipes,* is poorly understood. Authors tend to agree that subterranean termites probably move downwards in the soil as the winter approaches (Myles and Grace 1991; Esenther 1969). Observations have also been made suggesting termites may overwinter by aggregating within large food resources occurring at the soil surface (Grace 1996). However, it is possible that as termites become less active with falling temperatures, they become trapped within the food resources they are exploiting, giving the false impression that they had aggregated.

It was found in this experiment that *R. flavipes* did not aggregate within the readily available food sources as ambient temperatures fell, nor did they show any tendency to preferentially assemble or cluster in just one food source. Direct observations clearly showed that *R. flavipes* continued to forage as the temperature fell from 20 to 10°C. As the temperatures fell from 10 to 5°C, there was a visible reduction in termite foraging activity, though the termites still did not aggregate. As the temperatures fell below 5°C, there was a noticeable accumulation of termites within the galleries at the bottom of the tubs.

There is a possibility that the cardboard rolls cooled more quickly than the surrounding soil, establishing a temporary thermal gradient within the tubs at the beginning of each temperature regime. This would not have been detected during the temperature recording, which was done on the ninth day of each temperature regime. If so, then it is possible that the termites may have moved from the rolls into the warmer soil in an attempt to locate a more hospitable environment.

This experiment found that termites do not aggregate within available food resources in response to falling temperatures and, consequently, no evidence was found to support the hypothesis that termites socially aggregate to share and retain metabolic heat. These experiments, however, may not have adequately simulated the termites subterranean environment and the actual soil temperature conditions. In future studies, it may be desirable to use a deeper soil column and termite-excavated solid wood, rather than wood wafers. Furthermore, using pre-installed temperature sensors would help to minimize the disturbance. It remains a possibility that under the right conditions, termites might form aggregations and their combined metabolic activity could result in isolated pockets of elevated temperatures for overwintering.

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INTRASPECIFIC LARVAL COMPETITION AND BROOD PRODUCTION IN *TOMICUS PINIPERDA* (L.) (COL., CURCULIONIDAE, SCOLYTINAE)

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Abstract *Proc. ent. Soc.* 128: 19-26

The pine shoot beetle, *Tomicus piniperda* (L.) (Col., Curculionidae, Scolytinae), is a pest recently introduced into Ontario, for which we have little information. The present study used naturally-infested trees (1995) and trap logs (1996) near Guelph, Ontario to examine larval competition and the establishment of successful galleries for this species. Gallery density (number of egg galleries per m^2 bark surface area) was highly variable but differed significantly between years. Mortality in the galleries was generally high, 50.6% in 1995 and 86.3% in 1996, suggestive of intense intraspecific competition. Significantly more new adults (11.6 vs. 5.1 beetles per gallery) were produced from each gallery at lower (83.3 galleries per m^2) than at higher (220.9 galleries per m^2) gallery densities. The number of beetles produced per gallery was inversely related to the density of galleries only at high gallery densities (1996). The number of beetles produced per square metre of bark was similar in both years, around 900 new beetles per m^2, despite variation in gallery density. Comparison of these results to those from its native range in Europe suggest that *T. piniperda* is reproducing successfully here and should continue to increase in size and range.

Introduction

The pine shoot beetle, *Tomicus piniperda* (L.) (Col., Curculionidae), is a widely distributed pest that has only recently been introduced into Ontario. An established population was first found in Ohio in July 1992, and it has since been found in eight U.S. states and in 13 counties in the Great Lakes region of Ontario attacking several native pines, as well as its primary host, Scots pine (*Pinus sylvestris* (L.)) (Haack 1996). *T. piniperda* is a major pest of Scots pine in Europe, establishing galleries in weakened trees or freshly cut logs early in the spring (Långström and Hellqvist 1993). Appropriate brood material releases allelochemicals that attract the parental beetles that are emerging from overwintering (Tunset *et al.* 1993). Females construct the main gallery chambers, the larvae feed on the inner bark layer and then pupate in the bark. Infested brood material can produce large numbers of beetles that then feed on shoots in the tree crowns for about three months (Fagerström *et al.* 1977; Långström 1983). Unlike tree-killing bark beetle species, the majority of the damage and growth loss is caused by this maturation shoot feeding, and not by the reproductive phase of the beetle's life cycle.

Brood material is often limited and widely spaced, causing competition among the parental generation and, especially, among the developing larvae (Huffaker *et al.* 1984). The present paper examines the relationship between gallery density and beetle production per gallery and per unit area (brood production) to assess the level of intraspecific larval competition in *T. piniperda*. In addition, because such recently introduced species can reach high levels in the absence of mortality factors (Speight and Wainhouse 1989), the reproductive potential of these beetles was compared to that in Europe to predict how successful they may become in southern Ontario.

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Materials and Methods

Study Sites. Reproduction of *T. piniperda* was studied during 1995 and 1996 in a 40-year-old Scots pine stand south of Guelph, Ontario (43°30′latitude, 80°20′ longitude). The height of the trees ranged from 13-17 m, and their DBH (diameter at 1.3 m height) from 14-18 cm. This stand was originally planted for erosion control with variable spacing.

Gallery Measurements. In December 1995, six naturally-infested Scots pine trees were felled and cut into approximately 1-m logs. All logs (n=15) with rough corky bark from the lower portion of the tree were brought to the laboratory. The number of exit holes and number of galleries in a 20-cm band on each log was recorded. Gallery length and number of egg grooves per gallery were measured for a representative sub-sample of 91 galleries from the 15 logs.

In March 1996, six trees which had been damaged by a storm the previous week were felled and cut into logs approximately 0.75 m long. A total of 28 logs were placed into eight separate piles of 3-4 logs each and left in the field for natural infestation by *T. piniperda*. In August 1996, after the beetles had completed development, six of these logs were brought to the laboratory and the number of exit holes and number of galleries in a 20-cm band on each log was recorded. Gallery length and number of egg grooves per gallery were then measured for a representative sub-sample of 25 galleries from the six logs.

Gallery density for both years was calculated as the number of galleries per square metre of bark surface area. Production of new adults per gallery, approximated as the number of exit holes per gallery, was calculated by dividing brood production (number of exit holes per square metre) by gallery density for each log sample. Measuring exit holes, and not adult offspring directly, tends to underestimate the population by approximately 10% because some holes are not visible and because a small number of beetles emerge through the same holes (Salonen 1973). Total mortality from 1995 data could be approximated using the initial mean number of egg grooves per gallery (based on the representative sample of 91 galleries from the 15 logs) and the number of exit holes per gallery calculated for each of the 15 logs. In 1996, egg mortality was determined directly by counting the total number of egg grooves and the maximum number of larval tunnels visible for the sub-sample of 25 galleries from the six logs. Total mortality for 1996 was calculated using the initial mean number of egg grooves per gallery (using the sub-sample) and the number of exit holes per gallery calculated for each of the six logs.

Statistical Analyses. Mean gallery length, gallery density, production per gallery and brood production were compared between the two years using a non-parametric Mann-Whitney test (Zar 1984). The relationship between production of new adults per gallery and gallery density, and between brood production and gallery density, were both examined using a Spearman rank order correlation coefficient (SAS: PROC RANK, Spearman) (Zar 1984).

Results and Discussion

Mean gallery length was not significantly different between the two years; 79.5 ± 2.4 mm (mean ± s.d.) in 1995 and 74.1 ± 0.9 mm in 1996 (Table I). The final gallery length of *ca.* 7 cm which we

TABLE I. Comparison between 1995 and 1996 of the mean gallery length, mean number of eggs per gallery, mean gallery density, mean number of new adults per gallery and mean number of new adults per m^2 for *Tomicus piniperda.*

	1995	1996		
	Mean ± s.d. (n)	Mean ± s.d. (n)	U	p
Gallery length (mm)	79.5 ± 2.4 (91)	74.1 ± 0.9 (25)	1020.5	0.4342
No. egg grooves (/gallery)	22.8 ± 11.7 (91)	24.5 ± 8.7 (25)	783.2	0.5348
No. galleries (/m^2)	83.3 ± 31.1 (15)	220.9 ± 131.9 (6)	3.0	0.0006
No. exit holes (/gallery)	11.6 ± 6.4 (15)	5.1 ± 2.7 (6)	13.0	0.0144
No. exit holes (/m^2)	917.1 ± 460.1 (15)	905.0 ± 204.3 (6)	45.0	0.9690

observed corresponds well with previous European studies of *T. piniperda* reproducing on Scots pine where lengths ranged from 3-5 cm (Gibbs and Inman 1991), 7-8 cm (Långström 1983), 8-9 cm (Salonen 1973; Sauvard 1989), to 10.5 cm (Långström and Hellqvist 1985).

The number of eggs laid per gallery by *T. piniperda* was similar in both years; 22.8 ± 11.7 in 1995 and 24.5 ± 8.7 in 1996 (Table I). These means are considerably lower than previous European work where both Långström (1983) and Sauvard (1993) found an average of 40-50 eggs per gallery. Our data may have underestimated the actual value because the egg notches were difficult to ascertain, especially in 1995 when the brood material was 6-8 months old. Alternatively, there may be a true reduction in fecundity for females because of a possible loss of adaptedness associated with the beetle's recent immigration into North America.

The mean density of galleries produced by *T. piniperda* per square metre of log surface was significantly lower in 1995 (83.3 ± 31.1) than in 1996 (220.9 ± 131.9) (Table I). Previous work in Europe has shown the density of *T. piniperda* galleries per square metre to vary, from 25 to 300 (Långström 1983), 200-300 (Salonen 1973), to 496.8 (Långström and Hellqvist 1993). Both densities we obtained, therefore, fall well within the expected range for this species on its native host.

More new adults were produced per gallery at the lower gallery densities in 1995 (11.6 ± 6.4 exit holes/gallery) than at the higher densities in 1996 (5.1 ± 2.7) (Table I). The number of adults produced from individual galleries in Europe has also ranged, depending on the density of beetle attacks. Långström and Hellqvist (1993) found an extremely low number of holes per gallery (0.4) at very high beetle densities (496.8 galleries/m^2), as did Salonen (1973) (*ca.* 3 beetles/gallery at 301-400 galleries/m^2), while at low densities, 27-32 holes/gallery were recorded by Långström and Hellqvist (1985) and 30-35 holes/gallery were recorded by Salonen (1973) (at densities of 1-100 galleries/ m^2). Saarenmaa (1985) found 2.5-7 holes/gallery at gallery densities ranging from 24-179 galleries/m^2. Other European values range from 3-6 adults/gallery (Annila and Heikkila 1991) to 6.4 adults/gallery (Heliovaara and Vaisanen 1991), at intermediate gallery densities. Both years of data in our study fall within this range, demonstrating successful gallery production of *ca.* 2-6 new adults per parental beetle. This suggests that the beetle is establishing itself in Ontario, and doing as well as in its native European habitat.

Total mortality in the egg, larval, and pupal stage of *T. piniperda* was 49.1 ± 26.2% in 1995 (low gallery density) and 79.2 ± 11.0% in 1996 (high gallery density). In 1996, mortality of the egg stage alone averaged 16.5 ± 9.4%, meaning that mortality of the other stages (larvae, pupae and new adults) was *ca.* 62.7%. Intraspecific larval competition is considered to be the largest source of egg-to-adult mortality in bark beetles (Kirkendall 1989). Saarenmaa (1985) found the survival rates of the early larval instars to be very low. Hui and Zhimo (1995) found total mortality of *T. piniperda* from the egg to new adult stage to be 78%. Of this, only 3% and 2% occurred in the pupae and new adult stage, respectively. Most of the 78% mortality was attributed to the larval stage, with approximately half caused directly by intraspecific larval competition (Hui and Zhimo 1995). Low levels of pupal and new adult mortality are assumed to be constant at differing densities (Salonen 1973) because there is no shortage of space in which to pupate. Therefore, it is reasonable to assume that most of the 62.7% mortality in our study was larval mortality and that the additional mortality (30.1%) in 1996 over that in 1995 may have resulted from increased larval competition at the higher gallery densities. Indeed, Salonen (1973) found that larval mortality ranged from 12 to 91% as the densities increased from 63 to 325 galleries/m^2. Clearly, the larval stage is highly sensitive to the effects of gallery density and intense levels of intraspecific competition can occur.

Gallery production and density were not found to be significantly correlated at low gallery densities (35 to 135 galleries/m^2) in 1995 (Fig. 1a), however, at the higher densities (120 to 430 galleries/m^2) in 1996, density and gallery production were negatively correlated (Fig. 1b). At the lower densities, resource limitations were probably not being experienced and additional galleries could be initiated without influencing the success rate of surrounding galleries. In contrast, at the higher densities, production per gallery was reduced correspondingly with a large percentage of the variation in production levels (82.9%) explained by gallery density. This suggests that high gallery densities have a serious impact on larval survival, possibly through increased competition. Indeed, Salonen (1973) and Sauvard (1993) both found that increasing densities of *T. piniperda* galleries caused a serious decline in larval survival and production per gallery, when density exceeded a critical level. Saarenmaa (1985) also reported that the effects of important mortality agents of *T. piniperda* are positively density-dependent. This effect has been commonly found for other bark beetles, such as *Ips typographus* L. (Weslien 1994; Anderbrant *et al.* 1985) and *Dendroctonus ponderosae* Hopkins (Raffa and Berryman 1983).

In our study, total brood production was found to be the same in both years, with 917.1 ± 460.1 exit holes/m^2 in 1995 and 905.0 ± 204.3 holes/m^2 in 1996 (Table I), despite the highly variable gallery density and production per gallery. This suggests that the beetle is operating at or near its carrying capacity on Scots pine in southern Ontario. Previous European studies have reported average values of around 1000 beetles/m^2 for *T. piniperda* on Scots pine (Långström 1984; Heliovaara and Vaisanen 1991; Sauvard 1993 and 1989). This is further indication of the beetle's successful establishment, as it is doing as well here as in its native European range.

At the lower densities in 1995, brood production was positively correlated with gallery density (Fig. 2a), suggesting that mortality is density-independent over this lower range. However, brood production in 1996 was not found to be significantly influenced by gallery density (Fig. 2b), indicative that density-dependant mortality may be occurring at these higher densities. European studies have also shown that density-dependent effects limit the brood production of *T. piniperda*, primarily due to increased intraspecific larval competition for food and space (Salonen 1973; Beaver 1974; Långström 1984; Långström and Hellqvist 1985; Sauvard 1989; Heliovaara and Vaisanen 1991).

Our results indicate that *T. piniperda* is successfully reproducing on the brood material in southern Ontario, making effective use of the available resource of Scots pine. They also suggest that this species will continue to increase in numbers and expand its range. A variety of factors may be contributing to the successful establishment of this pest in Ontario. First, newly invading species can often be found operating at very high numbers because there are few constraints on their growth as natural enemies and appropriate host plant defenses are often lacking (Speight and Wainhouse 1989). Indeed, *T. piniperda* has only been in Ontario for 4-5 years (Haack 1996), so it is unlikely that many

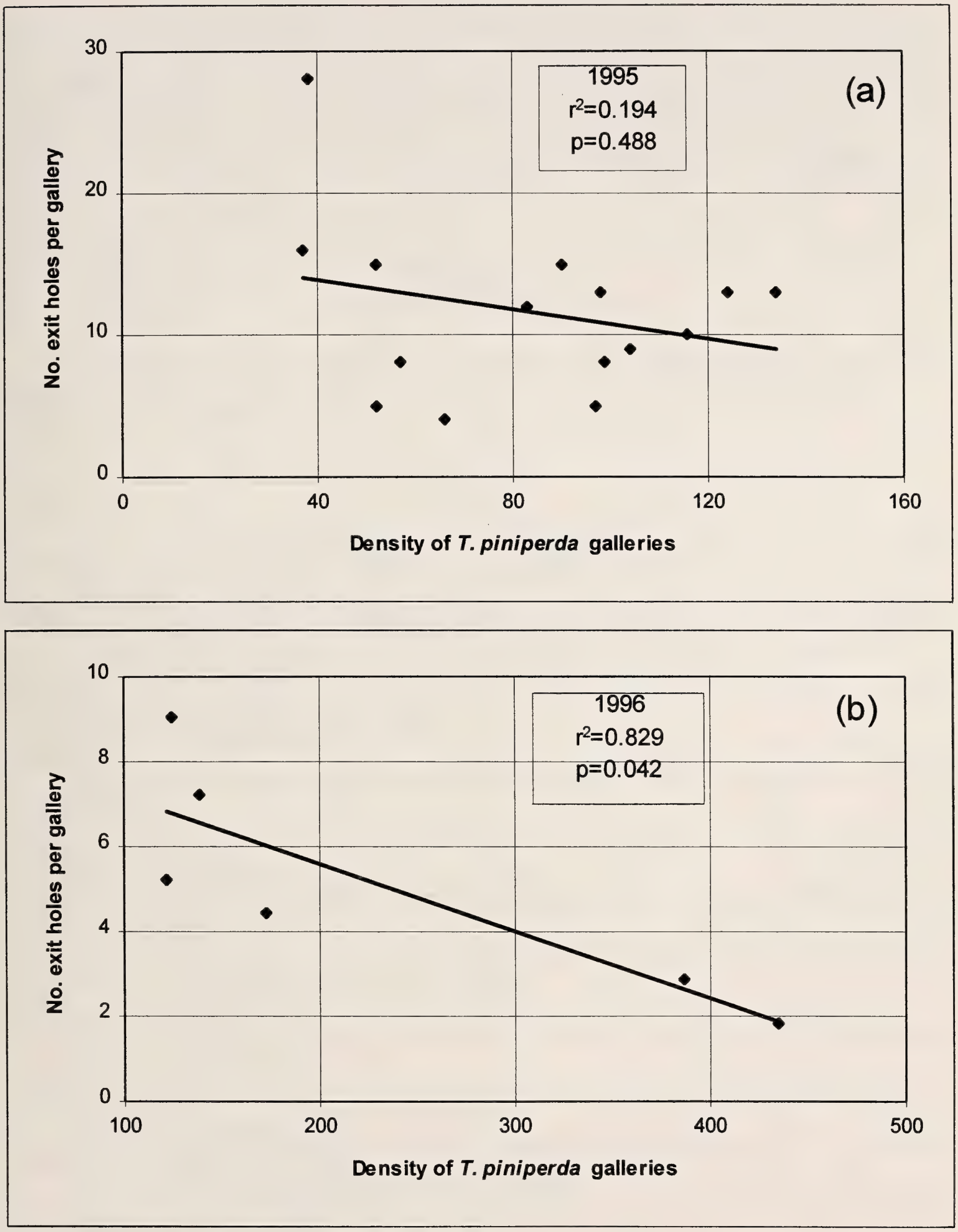

FIGURE 1. Relationship between the number of new *Tomicus piniperda* adults emerging per gallery and increasing gallery density on sections from (a) naturally infested standing Scots pine (*Pinus sylvestris*) trees (1995) and (b) cut Scots pine logs (1996) in a 40-year-old stand near Guelph, Ontario. Note difference in scale of x and y axis.

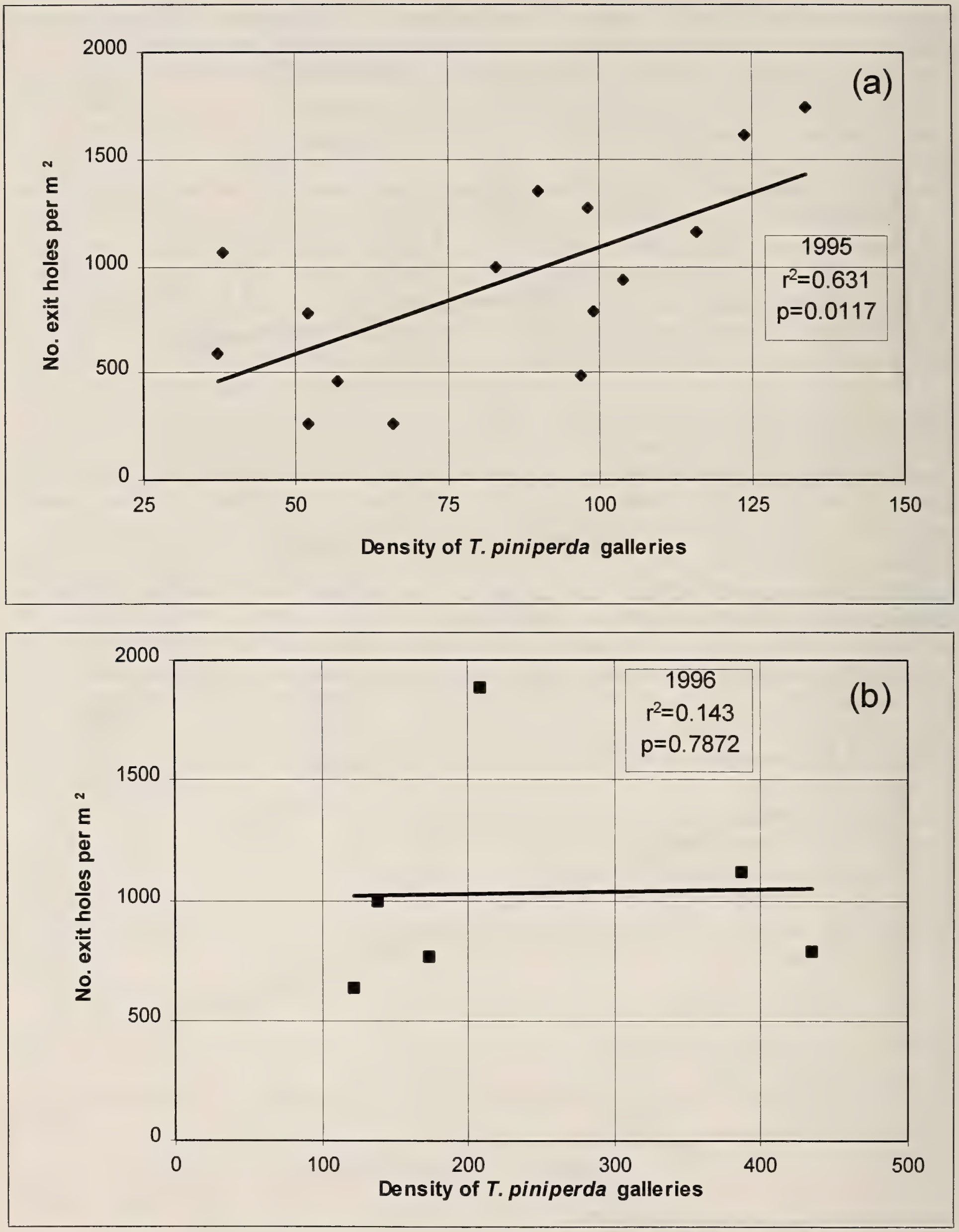

FIGURE 2. Relationship between the number of new *Tomicus piniperda* beetles emerging per square metre and gallery density on (a) naturally infested standing Scots pine (*Pinus sylvestris*) trees (1995) and (b) cut Scots pine trap logs (1996) in a 40-year-old stand near Guelph, Ontario. Note difference in scale of x axis.

predators or parasitoids have been able to utilize it effectively yet. Second, Scots pine, the primary host of *T. piniperda,* is itself originally from Europe, and such introduced species may be unusually stressed because of their relocation. In addition, these trees have often been planted on unsuitable habitat. These factors may increase their risk of attack by pests accidentally brought in from the original native habitat (Speight and Wainhouse 1989). Finally, because *T. piniperda* is already well adapted to Scots pine, it may easily out-compete other North American species of bark beetles attempting to colonize this host. Further work should examine these factors in detail as *T. piniperda* continues to spread and establish itself in Ontario.

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REVIEW OF THE GENUS *STEPHANODES* (HYMENOPTERA: MYMARIDAE)

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Abstract *Proc. ent. Soc. Ont.* 128: 27-63

The nomenclatural history of *Stephanodes* Enock is summarized. The genus is defined and compared to its probable sister genus, *Agalmopolynema* Ogloblin, and to *Polynema* Haliday, the common genus with which *Stephanodes* has been most often confused. *Masonana* Yoshimoto is treated as a new synonym of *Stephanodes*, and *Stephanodes polynemoides* (Yoshimoto) is treated as a new combination. One new species from North America, *S. septentrionalis* Huber, is described. *Stephanodes psecas* Girault is treated as a junior synonym of *S. similis* Förster, and *S. orientalis* Taguchi and *S. imbricatus* (Narayanan and Subba Rao) are treated as junior synonyms of *S. reduvioli* (Perkins). Lectotypes are designated for *S. elegans* Enock and *S. reduvioli*, and the problem of a previous lectotype designation for *S. similis* is discussed. The described species except for *S. chestertoni* (Debauche), whose type material is missing, are keyed.

Résumé *Proc. ent. Soc. Ont.* 128: 27-63

Nous résumons l'histoire nomenclatrice de *Stephanodes* Enock. Nous redéfinissons le genre et le comparons avec son adelphotaxon probable, *Agalmopolynema* Fidalgo, et avec *Polynema* Haliday, le genre le plus commun avec lequel *Stephanodes* a souvent été confondu. Nous reconaissons *Masonana* Yoshimoto comme nouveau synonyme de *Stephanodes* et *S. polynemoides* (Yoshimoto) comme une combinaison nouvelle. Une nouvelle espèce d'Amérique du Nord, *S. septentrionalis* Huber, est décrite. Nous traitons *Stephanodes psecas* comme synonyme plus récent de *S. similis* Förster, et traitons *S. orientalis* Taguchi et *S. imbricatus* (Narayanan and Subba Rao) comme synonymes plus récents de *S. reduvioli* (Perkins). Nous désignons des lectotypes pour *S. elegans* Enock and *S. reduvioli* et discutons du problème engendré par la désignation antérieure d'un lectotype de *S. similis*. Nous présentons également une clé d'identification des espèces décrites, avec exeption de *S. chestertoni* (Debauche) dont les types manques.

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Introduction

The genus *Stephanodes* (Hymenoptera: Mymaridae), with only a few described species, has been collected on all continents and many oceanic islands. Its nomenclatural history is complicated because it is superficially similar to *Polynema* Haliday with which it has often been confused. Previous generic descriptions often are long and detailed and the few critical features that distinguish *Stephanodes* from other genera of Mymarini *sensu* Annecke and Doutt (1961) are hidden among many other features in common with other genera.

This project was initiated when PF was revising the Ogloblin collection in La Plata, Argentina, and found a series of 29 slide-mounted specimens from Argentina identified by Ogloblin as *Stephanodes*, some bearing manuscript names. This material was studied as well as specimens of *S. similis* from Europe and some collected by PF in northern Argentina. The first author was then asked to contribute to the study, which was expanded to a world review.

The main purpose of this paper is to clarify the taxonomy of *Stephanodes*, and provide an illustrated generic diagnosis and a new synonym. Additionally, we briefly review its taxonomic history, present descriptive notes and distributional information on the described species, and give a revised key to most of them. Two distinctly new species are discussed, one of which is formally described. A complete species level revision is not attempted because much more material needs to be collected and properly slide-mounted before this can be done meaningfully. Typically, and perhaps predictably, more nomenclatural and taxonomic problems were encountered than were initially expected. Solutions to some only are provided here. The main problems revolve around the majority of specimens which resemble, or are identical to, either *S. similis* or *S. reduvioli*.

Methods

Measurements, in micrometers, of slide-mounted specimens are tabulated (Table I). In all cases, the mean is followed in parentheses by the range and number of specimens measured. Flagellar segments were measured from the apex of the previous segment. Thus, the short section of a given funicle segment that is inserted into the apex of the previous segment (only visible in slide mounts) is not included. Abbreviations used are: F for female funicle or male flagellum, FWL, FWW, HWL, HWW, for length and width of fore- and hindwings, respectively.

Specimens for scanning electron microscopy (SEM) were prepared following Bolte (1996). Microscope slides of wings were photographed with a Lumina™ digital camera. The SEM micrograph negatives were scanned into a computer with a 35mm scanner. Both micrographs and wing images were digitized, enhanced, and the final plates compiled and labelled using Adobe Photoshop™ software.

Island group names listed in the Material Examined section follow Motteler (1986). Specimens were seen from the following institutions:

BMNH	The Natural History Museum, London. J. Noyes.
CISC	California Insect Survey, Division of Entomology, University of California, Berkeley. R. Zuparko.
CNCI	Canadian National Collection of Insects, Ottawa. J. Huber
DEFW	Department of Entomology, Fisheries, and Wildlife Collection, University of Minnesota, St. Paul. P. Clausen.
HDOA	Department of Agriculture, State of Hawaii, Honolulu. B. Kumashiro.
IARI	Division of Entomology, Indian Agriculture Research Institute, New Dehli. S. Farooqi.
IFML	Intituto Fundación Miguel Lillo, Tucumán. P. Fidalgo.
INHS	Illinois Natural History Survey, Urbana. K.C. McGiffin.

MHNG	Museum d'Histoire Naturelle, Geneva. I. Löbl.
MLPA	Museo de la Plata, La Plata. R. Ronderos.
MZLU	Museum of Zoology, Lund University, Helgonavagen. R. Danielsson.
NLHW	Naturhistorisches Museum Wien, Vienna. S. Schödl.
QDPI	Queensland Department of Primary Industries Insect Collection. B. Cantrell.
QMBA	Queensland Museum. E.C. Dahms.
TAMU	Texas A. and M. University, College Station. J. Woolley.
USNM	United States National Museum, Washington, D.C. M. Schauff.
UWEM	Department of Entomology, University of Wisconsin, Madison. S. Krauth.

Nomenclatural History

The rather complex history of *Stephanodes* is due partly to the confusion over the type species of *Polynema*, with a consequent mixup of names, and partly to Girault's (1911, 1912b, 1913) and Soyka's (1946) definition of the generic limits of *Polynema*. Though the limits of *Polynema* on a world basis are still not clear, Graham (1982) notwithstanding, those of *Stephanodes* are. Defining several of the species within *Stephanodes*, however, remains a challenge.

Shortly after Enock (1909) described *Stephanodes*, Girault (1911) synonymized it with *Polynema*. Girault (1912a, 1912b, 1913), continued to treat *Stephanodes* as a synonym of *Polynema* as did Bakkendorf (1934) and Soyka (1946), though Soyka (1956) finally treated it as distinct. Debauche (1949) incorrectly used the name *Polynema* for *Stephanodes*, having been influenced by some incorrect species synonymies proposed by Soyka (1946). Kryger (1950) used the name *Stephanodes* though he considered that there was no justification to maintain it separately from *Polynema*. Narayanan and Subba Rao (1961) treated *Stephanodes* as a subgenus of *Polynema*. Ogloblin (1946: 282) provided an important diagnostic feature for *Stephanodes*: the advanced mesothoracic spiracle, located on the suture between the pronotum and mesoscutum (Fig. 14). Since then the genus has been treated as distinct from *Polynema* by Debauche (1948), Hincks (1950), Annecke and Doutt (1961), Mathot (1968), Graham (1982), Bouček (1977), Fitton *et al.* (1978), Taguchi (1978), Subba Rao and Hayat (1983), Schauff (1984), Huber (1986), Noyes and Valentine (1989), Yoshimoto (1990), and Hayat (1992).

Biology

Known hosts of *Stephanodes* are Nabidae (Hemiptera) but one record from Cicadellidae (Homoptera) is reported here. Perkins (1905) recorded his new species *Polynema reduvioli* from eggs of *Reduviolus blackburni* (Kirkaldy) in Hawaii, and Timberlake (1924) recorded the same species from eggs of *Reduviolus capsiformis* (Germar). Thompson (1958) listed *Nabis blackburni* as the host of *Polynema reduvioli* in Australia and *N. capsiformis* in Hawaii. The predaceous *R. blackburni*, however, is apparently endemic to the Hawaiian Islands. It is generally distributed among the islands and is abundant in sugarcane fields (Swezey 1936). Thompson's citation from Australia is based on a misidentification of the host by Kirkaldy (Beardsley, pers. comm.). Kerzhner (1981) classified the cosmopolitan *R. capsiformis* as *Nabis* (*Tropiconabis*) and synonymized *N. blackburni* (Kirkaldy) with it. This synonymy is incorrect because presumably it was again based on the misidentification by Kirkaldy. Because *Nabis* is widespread (Kerzhner 1981) it is possibly also the host genus for other species of *Stephanodes* in other parts of the world. Species of only two other genera of Mymaridae, *Polynema* and *Anaphes*, are known for certain to parasitize Nabidae (Kerzhner 1981; Huber and Rajakulendran 1988).

TABLE I. Descriptive statistics for species of *Stephanodes*. Measurements in µm. Abbreviations used: FW=fore wing; HW=hind wing; L=length; W=width; ssd=sample standard deviation, postal abbreviations for provinces and states.

S. similis (Europe)
(Austria, Belgium, Czech Republic, England, Germany)

Character	n	Mean	Range	SSD
Head W	3	274	253-300	23
Gastral petiole L	9	182	158-210	17
Ovipositor L	20	287	253-316	13
Hind tibia L	20	413	355-457	23
Forewing L	11	1277	1226-1367	48
Forewing W	9	340	325-367	13
Forewing L/W	9	3.72	3.53-3.94	0.13
Scape + radicle L	5	98	93-101	3
Pedicel L	22	53	51-58	3
F1 L	21	89	79-98	5
F2 L	23	100	86-114	7
F3 L	21	75	68-81	4
F4 L	23	64	55-73	2
F5 L	22	64	55-72	1
F6 L	21	62	55-71	4
Clava L	19	141	128-144	5
Flagellum L - male	7	1359	1212-1500	138
F5 L - male	9	124	107-149	17
F5 W - male	9	28	26-32	2
F5 L/W male	9	4.47	3.35-5.83	0.9

S. similis [= *S. psecas*] (Canada - ON, QU,
United States - MO, WI, MN, IL IA)

Character	n	Mean	Range	SSD
Head W	5	233	223-239	7
Gastral petiole L	10	177	160-203	15
Ovipositor L	10	314	280-350	23
Hind tibia L	10	384	349-430	25
Forewing L	13	1202	1091-1363	338
Forewing W	12	321	285-384	32
Forewing L/W	12	3.74	3.49-4.14	0.2
Scape + radicle L	5	100	89-105	6
Pedicel L	10	53	50-58	3
F1 L	12	95	84-109	7
F2 L	12	99	86-107	8
F3 L	10	74	62-82	6
F4 L	11	62	54-78	7
F5 L	13	63	58-69	4
F6 L	13	62	56-68	4
Clava L	11	143	134-159	7
Flagellum L - male	2	1251	≈1191-1311	85
F5 L - male	2	116	109-124	11
F5 W - male	2	28	28-29	1
F5 L/W male	2	4.14	3.93-4.35	0.3

TABLE I. - continued

S. similis (Argentina)

Character	n	Mean	Range	SSD
Head W	5	225	216-235	10
Gastral petiole L	-	-	-	-
Ovipositor L	3	206	178-225	26
Hind tibia L	8	364	353-372	10
Forewing L	8	1163	1121-1210	33
Forewing W	8	294	284-304	10
Forewing L/W	8	3.95	3.88-4.04	0.1
Scape + radicle L	8	68	57-78	8
Pedicel L	8	46	39-51	4
F1 L	7	78	70-86	6
F2 L	7	99	98-101	1
F3 L	7	72	66-74	3
F4 L	7	60	59-62	2
F5 L	7	58	56-62	2
F6 L	8	58	55-59	2
Clava L	8	144	140-148	4
Flagellum L - male	2	1136	-	0
F5 L - male	2	267	265-270	3
F5 W - male	2	76	74-78	3
F5 L/W male	2	3.52	3.43-3.6	0.1

S. reduvioli (Hawaiian Islands - Kure Atoll to Molokai I.)

Character	n	Mean	Range	SSD
Head W	3	229	227-233	3
Gastral petiole L	9	162	143-182	13
Ovipositor L	11	264	235-280	12
Hind tibia L	9	362	295-397	31
Forewing L	10	1194	1088-1282	58
Forewing W	10	301	224-346	33
Forewing L/W	10	3.87	3.61-3.97	0.2
Scape + radicle L	6	93	82-97	5
Pedicel L	11	52	33-57	7
F1 L	10	82	72-88	5
F2 L	10	97	92-110	6
F3 L	11	71	60-76	4
F4 L	11	59	49-66	5
F5 L	11	60	50-66	4
F6 L	11	62	50-68	5
Clava L	10	149	143-154	3
Flagellum L - male	3	1086	999-1191	97
F5 L - male	3	202	182-226	22
F5 W - male	3	62	55-65	6
F5 L/W male	3	3.3	2.8-4.1	0.7

TABLE I. - continued

S. reduvioli (Northern Mariana Islands - Saipan) (males not available)

Character	n	Mean	Range	SSD
Head W	9	228	216-246	8
Gastral petiole L	7	154	141-174	11
Ovipositor L	13	268	256-278	7
Hind tibia L	9	348	310-360	17
Forewing L	13	1049	962-1094	40
Forewing W	14	254	227-266	11
Forewing L/W	12	4.13	3.99-4.27	0.08
Scape + radicle L	9	92	82-101	6
Pedicel L	14	52	49-56	2
F1 L	14	79	74-86	3
F2 L	15	92	72-96	6
F3 L	15	68	59-73	3
F4 L	15	59	51-65	4
F5 L	13	56	49-61	3
F6 L	14	59	52-63	3
Clava L	14	140	126-145	5

S. reduvioli [= *S. imbricatus*] (India) (males not available)

Character	n	Mean	Range	SSD
Head W	-	-	-	-
Gastral petiole L	3	158	148-167	10
Ovipositor L	3	268	255-290	19
Hind tibia L	3	354	348-367	11
Forewing L	3	1167	1108-1267	86
Forewing W	3	308	299-323	14
Forewing L/W	3	3.8	3.70-3.92	0.11
Scape + radicle L	3	99	95-104	4
Pedicel L	3	55	54-56	1
F1 L	3	83	80-88	5
F2 L	3	93	87-98	5
F3 L	3	69	66-74	4
F4 L	3	58	54-61	4
F5 L	3	62	60-63	2
F6 L	3	63	61-64	1
Clava L	3	150	147-154	3

TABLE I. - continued

S. missionicus (Ogloblin) (males unknown)

Character	n	Mean	Range	SSD
Head W	2	267	266-268	1
Gastral petiole L	2	247	237-256	13
Ovipositor L	1	323	-	-
Hind tibia L	1	528	-	-
Forewing L	3	1606	1583-1636	27
Forewing W	3	521	505-540	18
Forewing L/W	3	3.08	3.03-3.17	0.08
Scape + radicle L	1	109	-	-
Pedicel L	2	46	45-47	2
F1 L	3	100	97-103	3
F2 L	3	117	116-118	1
F3 L	3	107	101-110	5
F4 L	3	89	86-90	2
F5 L	3	89	88-90	1
F6 L	3	80	79-81	1
Clava L	3	210	196-218	12

S. septentrionalis Huber sp. n.

Character	n	Mean	Range	SSD
Head W	1	232	-	-
Gastral petiole L	2	220	200-240	28
Ovipositor L	3	314	300-325	13
Hind tibia L	2	430	364-495	93
Forewing L	3	1360	1175-1459	160
Forewing W	3	451	364-495	76
Forewing L/W	3	3.03	2.92-3.23	0.17
Scape + radicle L	2	104	103-106	1
Pedicel L	3	61	57-63	3
F1 L	3	81	71-89	9
F2 L	3	98	84-107	13
F3 L	3	81	68-89	11
F4 L	3	70	58-77	11
F5 L	3	71	60-77	10
F6 L	3	67	58-72	8
Clava L	3	152	135-163	16
Flagellum L - male	3	1344	1320-1389	39
F5 L - male	7	124	111-131	7
F5 W - male	7	27	23-31	3
F5 L/W male	7	4.57	4.0-5.39	0.51

The basis for the single cicadellid record is one female (BMNH) reared on 16.xi.1979 from *Nilaparvata lugens* (Stål) at the International Rice Research Institute, Los Baños, Philippines, by A.T. Barrion. Given the importance of this host, and the many studies on its biology, it is surprising that more records of *Stephanodes* from that pest have not been published. The host association therefore needs to be confirmed.

Taguchi (1978), cited also by Noyes and Valentine (1989), mentioned Membracidae as a host for *Stephanodes* but this was based on the incorrect inclusion of *Polynema striaticorne* in *Stephanodes*; *P. striaticorne* is reported from *Ceresa.*

Stephanodes species occur in a wide variety of habitats, including deciduous forests, bogs, marshes, and grasslands. But apart from the above host records, the biology of *Stephanodes* is unknown. Enock mentioned that live *S. elegans* had a totally different gait from *Cosmocoma* (*=Polynema*).

Taxonomy

Stephanodes Enock, 1909: 457. Type species: *Stephanodes elegans* Enock, 1909: 457, Plate XIV, figs. 6-11. By monotypy.

Eustephanodes Ogloblin, 1967: 194. Type species: *Eustephanodes missionicus* Ogloblin, 1967: 194. By original designation. Synonymized under *Stephanodes* by Yoshimoto (1990).

Masonana Yoshimoto, 1990: 63. Types species: *Masonana polynemoides* Yoshimoto, 1990: 64. By original designation. **Syn. n.**

The genus *Stephanodes* has been described or diagnosed several times in varying degrees of detail and with discussion of related genera (Debauche 1948 and 1949; Hincks 1950; Soyka 1956; Annecke and Doutt 1961; Noyes and Valentine 1989). Rather than give yet another lengthy redescription, we present here only the general habitus features and the specific diagnostic characters that distinguish it from related *Polynema*-like genera, and supplement these with Figs. 1-60. The sister genus to *Stephanodes* is likely *Agalmopolynema*, illustrated by *A. mirabile* Fidalgo (Figs. 61-92). *Agalmopolynema* was initially treated as a subgenus of *Barypolynema* (Ogloblin 1960a, 1960b); the diagnostic features of *Stephanodes* given below are compared and contrasted with it. Fidalgo (1988) gave *Agalmopolynema* generic rank; its 16 species are currently only known from the *Nothofagus* zone of South America, an area from which *Stephanodes* has not yet been reported, though a specimen of *S. reduvioli* has been collected at the edge of *Nothofagus* forest in New Zealand. In contrast, *Polynema* is a much more common and widely distributed genus than *Agalmopolynema*, with a worldwide distribution that completely overlaps that of *Stephanodes*. Though *Polynema* is not the sister genus of *Stephanodes*, it is with *Polynema* that *Stephanodes* has most often been confused. Therefore, the diagnostic features of *Stephanodes* are also contrasted with *Polynema*. This should serve to make the two genera easily separable henceforth.

The superficial similarity of the three genera is due to their colour and general profile — all the species are relatively gracile. All known species of *Stephanodes*, as well as many *Agalmopolynema*, *Polynema*, and various species of several other genera of Mymarini have the same body colour: dark brown to black with the first 3 antennal segments (scape, pedicel, F1), gastral petiole, and entire legs, except the dark brown last tarsal segment, orange to yellow.

Diagnosis. Distinguishing general features of *Stephanodes* species include the more globular head in anterior view (Figs. 3, 9) and the dorsum of the mesosoma usually more strongly and evenly curved in lateral view (Figs. 14, 20) and narrower (Fig. 13) and higher (more compressed) than in *Agalmopolynema* (Figs. 67, 68) and *Polynema*, thus clearly narrower than the head. The mesosoma and metasoma are uniformly smooth, shiny, and dark brown, with scape, pedicel, legs except apical tarsal segment, and petiole bright yellow. The forewing extends beyond the apex of the metasoma by at least 45% of its own length and thus appears relatively longer compared to the body than in *Polynema*. The wings often also appear to be disproportionately broad in some species.

Several details of the antenna, head, mesosoma, metasoma, and forewing together unequivocally define both sexes of the genus. However, any one of the features of *Stephanodes* listed below usually occurs in at least one other genus of Mymarinae, except for the nature and position of the mesothoracic spiracle (Figs. 13, 14) and the peculiar vertical slits ending in internal pits above the foramen magnum (Fig. 5), so several characters should be checked to ensure that the specimen at hand is indeed a *Stephanodes*. With practice, the genus becomes easily recognizable on general habitus features alone. Diagnostic features for *Stephanodes* (contrasting state is also given for *Agalmopolynema* and *Polynema*) are:

1. Front of head quite sharply bulging medially (as seen in lateral view), strongly depressed and receding medially above toruli and between eyes, giving the inner orbits a carinate appearance (Figs. 2, 8). Same in *Agalmopolynema* (Figs. 62, 64); flat or, at most, much less strongly bulging medially and at most slightly depressed above toruli in *Polynema*.
2. Subantennal grooves present (Figs. 3, 9). Grooves absent or scarcely indicated in *Agalmopolynema* (Fig. 63) and *Polynema*.
3. Face with 2 pits above and between toruli (Figs. 3, 9). Pits absent in *Agalmopolynema* (Fig. 63) and *Polynema*.
4. Vertex with large depressions outside each ocellus, the depressions wider and longer than an ocellus (Figs. 1, 3, 7, 9). With small depressions in *Agalmopolynema* (Figs. 61, 63); without depressions in *Polynema*.
5. Back of head with short, arched occipital carina above foramen magnum, and foramen magnum with two vertical dorsal slits extending to carina (Figs. 5, 11). Without occipital carina or vertical slits in *Agalmopolynema* (Fig. 65) and *Polynema*.
6. Antenna with inner surface of scape imbricate, with the individual imbrications not much wider than long (Figs. 44, 46, 49). With fine engraved reticulation in *Agalmopolynema* (Figs. 87, 89); at most with strongly transverse (much wider than long) striations in *Polynema*.
7. Female funicle with F1 almost always the longest, and remaining segments decreasing in length towards clava (Fig. 49); only one longitudinal sensory ridge (on F6) on the funicle. F1 shorter than F2 in *Agalmopolynema* (Fig. 90) and usually shorter than F2 in *Polynema*.
8. Prepectus fusiform, widest medially (Figs. 14, 20) and, in ventral view, relatively narrow (Figs. 15, 21). Prepectus triangular, widest dorsally (Fig. 68) and, in ventral view, relatively broad in *Agalmopolynema* (Fig. 69) and *Polynema*.
9. Marginal vein linear, with anterior and posterior margins parallel, and without proximal macrochaeta (Figs. 51, 53-60). Marginal vein linear to punctiform (Fig. 92) and with proximal macrochaeta in *Agalmopolynema*; vein swollen, punctiform, the posterior margin strongly curved and not parallel with anterior margin, and with proximal macrochaetae in *Polynema*.
10. Mesothoracic spiracle closer to anterior apex of notaulus than to tegula and virtually flush with surface (Figs. 13, 14, 19, 20). Spiracle closer to tegula and with a short stalk (perhaps only visible in scanning electron micrographs) in *Agalmopolynema* (Figs. 67, 68) and *Polynema*.
11. Propodeum smooth, without a longitudinal median carina (Figs. 18, 24). Propodeum usually without median carina in *Agalmopolynema* (Fig. 72); usually with more-or-less elongate median carina in *Polynema*.
12. Gastral petiole with a longitudinal ventral suture (Figs. 35, 38). With similar structure in *Agalmopolynema* (Fig. 81); without ventral suture in *Polynema*.
13. Metasoma with petiole apparently attached to gastral sternum, the suture between tergum 3 and sternum 3 well above petiolar insertion (Figs. 26-28, 30, 31). Structure similar in

Agalmopolynema (Figs. 73-75); petiole apparently joined to gastral tergum in *Polynema*, with the suture between tergum 3 and sternum 3 at level of petiolar insertion.

Discussion

Ogloblin (1967) proposed a new tribe, Stephanodini, for *Stephanodes* and his *Stenomymar*, as noted in his English abstract. Somehow he forgot to include his *Eustephanodes* (synonymized under *Stephanodes* by Yoshimoto 1990) in the new tribe and it is not clear from the text whether he meant to include it rather than *Stenomymar*. In any case, the tribe was to be distinguished by the position of the mesothoracic spiracle and the "subcuticular" pits on the frons, vertex and occiput. The pits on the frons are visible in some other genera, though their location is different. The pits on the vertex are actually large, shallow depressions that become deeper towards the ocelli and each ends in two pits, one on either side of each ocellus (visible in cleared slide-mounts). These pits perhaps contain glands or have a sensory function, as in some Scelionidae and Ceraphronoidea (Bin and Dessart 1983). The occiput bears two sets of pits. The relatively large pits just above the occiput may also be glandular or sensory. The very small pits just below the foramen magnum near the midline are the posterior tentorial pits, which are usually not visible in other genera. On the basis of a very similar head structure, *Stenomymar* may actually be the sister genus to *Stephanodes*, though features of the mesosoma suggest otherwise. Meanwhile, we consider *Agalmopolynema* to be the sister genus of *Stephanodes*. Previously, Ogloblin (1952) suggested that *Stephanodes*, together with *Polynema*, *Barypolynema* and *Acmopolynema*, should be placed in his new tribe Polynematini, which he distinguished from three other newly proposed tribes within the Mymarinae. Though *Stephanodes* is distinct from other genera of Mymarinae on the features listed above, such differences are not sufficient in our view to create yet another tribe, particularly when all his tribal concepts are based essentially on only the South American fauna, without reference to the Old World. Nevertheless, once the world fauna of all the "*Polynema*-group" of genera is examined in more detail, including all the new genera proposed since Ogloblin's time, his concept of tribes, modified to include genera from other regions, may prove to be one good way to classify the relatively numerous genera of Mymarinae.

Identification of the named *Stephanodes* species is difficult except for *S. polynemoides*, and perhaps also *S. septentrionalis* sp. n., described below. Annecke (1961) had similar identification problems with some apparently very widely distributed species of *Mymar*. Two species, *S. similis* and *S. reduvioli*, as we interpret them, are widespread; each apparently occurs on at least three continents, and each possibly consists of a complex of species, but if so we have not yet found reliable features to distinguish them. As mentioned above, *Nabis capsiformis*, the host of *S. reduvioli*, is widespread in the Pacific and presumably elsewhere which may account for the widespread occurrence of *S. reduvioli*. It may be that both *S. reduvioli* and *N. capsiformis* were introduced unintentionally through human activity to the various Pacific islands.

Only two keys to the species of *Stephanodes* have been published, and neither includes all of the described species. Debauche's (1948) key for Belgium treated only two species, *S. elegans* and *S. similis*. One is a synonym of the other; the characters he used to separate the two are variable. Taguchi (1978) included six nominal species in his key, also including *S. elegans* as separate from *S. similis*, and incorrectly included a species of *Polynema*. He mistakenly thought that *S. imbricatus* lacked a sensory ridge on F6 (it was not mentioned in the original description), which resulted in him describing a new species, *S. orientalis*, separated from *S. imbricatus* by the presence of a sensory ridge on F6. The other characters he used, such as relative lengths of the funicular segments in females, are variable and cannot reliably be used to separate the species.

One character not previously used to distinguish *Stephanodes* species is the number of sickle-shaped sensilla (Bin *et al.* 1989) on F3-F6 of the female antenna (Figs. 47, 48). This varies among specimens from different areas and may be a partial solution to distinguishing at least two of the species (or species complexes), even though there appears to be slight intraspecific variation in this character. Thus, female *S. reduvioli* and *S. similis* are separated on the basis of presence or absence of a sickle-shaped sensillum on F3. Males also have one or two sickle-shaped sensilla, on each of F4-F10 at least, but too few specimens were available to determine if consistent differences occur among the species. Other features not previously used are the degree and pattern of hairiness of the face, vertex, and gena. *Stephanodes polynemoides* appears to have distinctly more setae on the vertex, but fewer on the gena, than *S. septentrionalis*, for example.

The key presented below is incomplete because we have not seen specimens of *S. chestertoni*. It is, however, an improvement over Taguchi's (1978) key, if for no other reason than it excludes species of *Polynema*. Annecke and Doutt (1961) mentioned two species from South Africa, at least one of which is apparently undescribed. Two species from Malawi, possibly the same as the South African ones, are in the CNCI. One of these is very distinct from all remaining specimens studied so it is included in the key but not described until more material becomes available (only one specimen was examined).

Key to females of *Stephanodes*
(excluding *S. chestertoni*)

1 Forewing with 3 distinct dark spots well beyond venation (Fig. 54, and Yoshimoto (1990) fig. 88) . . . . *polynemoides* (Yoshimoto)
- Forewing without distinct dark spots, the disc either clear (Figs. 55-60) or at most with a slightly darker, transverse band just beyond apex of venation (Figs. 53) 2

2(1) Forewing relatively broad, L/W at most 3.3 (Figs 53, 60) 3
- Forewing relatively narrow, L/W at least 3.5 (Figs. 55-59) 4

3(2) Forewing with a darker transverse band just beyond apex of venation (Fig. 53); funicle with F1 yellow, F2-F6 dark brown, though sometimes F2 paler . . . . *septentrionalis* sp. n.
- Forewing uniformly clear beyond venation (Figs. 55-60); funicle with F1 - F5 yellow, F6 dark brown . . . . *missionicus* (Ogloblin)

4(2) Petiole over 0.6 times as long as gaster (148:228mμ), distinctly longer than metacoxa; mesosoma, excluding pronotum, 2.8 times as long as wide; gracile species with wings, legs and antennae unusually long; southern Africa . . . . undescribed sp.
- Petiole at most about 0.4 times as long as gaster, at most only slightly longer than metacoxa; mesosoma excluding pronotum, at most 2.2 times as long as wide; more robust species with wings, legs and antennae relatively shorter; worldwide 5

5(4) F3 with 1 sickle-shaped sensillum (Fig. 48), at least on one antenna . . . . . *reduvioli* (Perkins)
- F3 almost always without sickle-shaped sensilla, rarely apparently with 1 sensillum on one antenna . . . . *similis* (Förster)

Stephanodes similis (Förster)
(Figs. 47-52, 55, 56)

Polynema similis Förster, 1847: 218; Bakkendorf, 1934: 62; Soyka, 1946: 33; Debauche, 1948: 205.
Stephanodes similis; Debauche, 1948: 205; Hincks, 1950: 176; Mathot, 1968: 275; Viggiani, 1973: 277; Bouček, 1977: 123; Bouček and Fitton, 1978: 110; Taguchi, 1978: 75.

Stephanodes elegans Enock, 1909: 457; Soyka, 1946: 33; Debauche, 1948: 205; Hincks, 1950: 176; Mathot, 1968: 275; Bouček in Fitton *et al.*, 1978: 110; Taguchi, 1978: 75. Synonymized under *similis* by Soyka (1946).

Polynema elegans; Soyka, 1946: 33.

Polynema enockii Girault, 1911: 321; Soyka, 1946: 33; Hincks, 1950: 176; Mathot, 1968: 275. Replacement name for *P. elegans* (Enock), not Förster.

[*Stephanodes*] *enockii*; Bouček and Fitton, 1978: 110.

Polynema enocki; Debauche, 1948: 205. Misspelling.

(*Stephanodes*) *Polynema psecas*; Girault, 1911: 321 (nomen nudum); Girault, 1912a: 88 (nomen nudum).

Stephanodes psecas Girault, 1912b: 41; Debauche, 1948: 205; Taguchi, 1978: 75. **Syn. n.**

Polynema psecas; Debauche, 1948: 205.

Polynema isotoma Debauche, 1949: 7; Mathot, 1968: 275. Replacement name for *S. similis* (Förster).

Type material. *Polynema similis* ?Lectotype female (NLHW), not examined. Förster (1847) did not indicate the number of specimens he studied, where they were deposited, or which one was the "type". Part of his chalcidoid collection was sent via G. Mayr to the Vienna Natural History Museum (Horn and Kahle 1935) but some of Förster's *Stephanodes similis* specimens ended up both in Geneva and in London. Hincks (1950) stated that he had examined Förster's type, deposited in Geneva. Soyka (1956: 108) redescribed a female and a male of *Polynema similis*, both apparently without date or locality, from Vienna and stated that these specimens were a lectotype and allotype. He did not state whether he had remounted the specimens from the original minuten pins but judging from the detail in the lectotype description both specimens must have been on slides. They could not be found in Soyka's collection and neither could most of the 52 other specimens of *S. similis* listed by Soyka (1956) (Stefan Schödl, pers. comm.). Two of the 13 slide-mounted specimens loaned to us are labelled "para-type" and the remaining 10 "Typic. piece"; only 2 specimens (Hundsheim, 2.xi.1941 - see below) correspond with those listed in Soyka (1956). None, of course, is type material, but the fact that Soyka routinely labelled his specimens as some sort of type suggests that there may be a problem with his lectotype designation as well. His "allotype" designation would correctly be a paralectotype. However, until Soyka's lectotype and "allotype" are found to confirm that they really are original Förster specimens we cannot determine if his lectotype designation is valid. If it is not, then a lectotype from Förster's material in Geneva could be designated as indicated below.

Eight syntypes were examined (BMNH, MHNG). If Soyka's designations are correct (see above) there should be at least another two syntypes in NLHW. One of us (JH) reexamined the six *Stephanodes* in MHNG and concluded that they are indeed Förster's types, or at least part of his type series which included at least one female and one male, as is apparent from his original description. The two Förster specimens in London arrived with the R. von Stein collection (see below). The condition of the six Geneva specimens is as follows. Two female specimens each on its own corroded minuten pin and placed together on a cork strip on a single pin are labelled 1."*Cosmocoma similis* A. Foerst." 2."Foerster Type." 3."Type"(red label). One of the specimens lacks the gaster, some legs, and the wings, and is dirty. The second specimen appears to be complete but is so covered in dirt and webs that it cannot be examined properly. The complete specimen could be designated as the lectotype if necessary. The second pin has a minuten pin bearing one female and is labelled simply "Coll. Förster". The third pin bears two intact females and one male with the apical flagellomeres missing, each on its own minuten pin and is labelled "*Cosmocoma similis* Frst." Paralectotype labels were added to the second and third pins by JH. The two BMNH specimens are on two minuten pins on a *Polyporus* strip on a single pin. The condition of the minutens and specimens is the same as for the Geneva specimens. In addition to the original "*Cosmocoma similis* Frst." label, three other, more recently added labels read: 2."Germany (?Aachen) coll. A. Forster." 3."R. von Stein Coll. B.M. 1935-271". 4."*Stephanodes* *similis* (Forst.)." One of the specimens, probably a female, lacks both antennae, the left forewing, and right hind tarsus. The other, definitely a female, is complete. A red paralectotype label has been added to the pin by JH.

Polynema elegans. Lectotype female (BMNH), examined and here designated. Enock (1909) did not designate a holotype. The lectotype was slide-mounted by Enock and is labelled: 1. "*Stephanodes elegans* ♀ Type". 2."Woking July /85. FE." 3."Pl.XIV fig. 7". 4."enockii". A red label reading "*Stephanodes elegans* Enock Lectotype ♀ des. Huber 1997" has been added to the slide. A male slide, similarly labelled, except "fig. 6", has been labelled as one of the paralectotypes. Enock also mentioned specimens collected by Waterhouse in 1907, and Gooch in Somerset (no date) but did not indicate how many he had. There are 15 card-mounted specimens (6♀♀ and 9♂♂) from Burnham Beeches (BMNH) but only the five specimens collected in 1907 clearly form part of the syntype series and are labelled and here designated as paralectotypes. Their collection dates are 10.ix (3♂♂), 19.ix (1♂), and 30.ix (1♂). The remaining Waterhouse specimens are listed under Material Examined. The Gooch specimen(s) were not seen; at least some of them should be designated as paralectotypes when they are located.

Stephanodes psecas. Lectotype ♀ (INHS), designated by Frison (Webb 1980), examined. In fair condition, mounted laterally with head partly crushed and F5-clava of right antenna missing. On slide labelled: 1."*Stephanodes psecas* Girault 44209 Types ♀. Ill. 51485 1990" 2."Butler, 15.vii.1910 Urbana, vi.8.1910 44209 Sweeping." 3."*Polynema psecas* (Girault)". 4."LECTOTYPE *Stephanodes psecas* ♀ Girault." 5."PARATYPE *Stephanodes psecas* ♀ Girault." The "paratype" is correctly a paralectotype. The head is detached and two legs are missing but the specimen is otherwise in good condition.

Diagnosis. The absence of a sickle-shaped sensillum on F3 separates most *S. similis* from most *S. reduvioli* (sensillum present on F3), the species most closely related to it. Unfortunately, a few specimens of *S. similis* have this sensillum on one antenna and a few of *S. reduvioli* lack it, so the feature is not completely reliable. No completely reliable feature was found that separates all specimens of *S. similis* from all of *S. reduvioli*. Specimens that have a sickle-shaped sensillum on only one antenna are therefore placed in one or other species on the basis of provenance and specimens collected at the same locality that clearly fall in one species or the other as defined here.

Descriptive notes. Measurements of the antennal segments for both sexes and forewings are given in Table I. Debauche's (1948) detailed redescription of *S. similis* includes many features common to most *Stephanodes*. One mistake, perpetuated in Taguchi's (1978) key to species, was that Debauche did not notice that F6 of the antenna bears 1 sensory ridge, as do all species of *Stephanodes*. The sensillum is difficult to see and often is not visible depending on the antennal position in slide mounts.

Variation. Colour varies slightly. A specimen from Spain has the petiole, legs, and scape, pedicel and F1 light brown instead of yellow.

Differences in the mean length of the male flagellum occur among the populations from eastern North America, Europe, and Argentina (Table I). The funicle segments in males of *S. psecas* average slightly longer than in *S. similis*, as pointed out by Girault (1911), but there is overlap between the two populations. We prefer to treat the various populations as representing a single species in this case, particularly because the sample size for each population is too small to make reliable inferences, and there is considerable overlap in individual measurements.

Occasionally a sickle-shaped seta is found on F3 of one antenna (one of 13 slide-mounted eastern North American females, three of 24 of European females) and 2 specimens apparently had the seta on F3 of both antenna (two Austrian specimens in NLHW).

Girault (1911, 1912a, 1913) mentioned several features to separate *S. similis* from *S. psecas* but none of them appears to be valid. He also contradicted his own observations, as noted below.

1. Girault (1911, 1912a) stated that *S. psecas* has F1 less than F2 and F5 shortest of the last three segments whereas *S. similis* has F1 greater than F2 and F5 longest of the last three segments. Half of the female *S. psecas* we measured (6 of 12) have F1 longer than F2, and the other half have F1 shorter than F2. In *S. similis* all 24 specimens had F2 longer than F1. In female *S. psecas* none of 12 specimens has F5 the shortest of the apical three funicle segments. Instead, they have different combinations such as two segments equal in length, others with F4 as the longest, and yet others with F5 or F6 the longest. In female *S. similis*, 6 of 23 specimens have F5 the longest, 13 have F4 the longest, and 4 have F6 the longest.

2. In male *S. psecas* mean flagellar length is less than for *S. similis* (Table I), the opposite of what Girault (1913) stated.

3. The mean length/width ratio of the forewing (Table I) is slightly less in *S. similis* than in *S. psecas*, the opposite of Girault's (1911) observation.

Our observations of the nominal species thus indicated greater variability than Girault was aware of and considerable overlap among the North American and European populations. We consider the two species conspecific, as Girault (1912b) had suspected.

Distribution. Europe, North America (Canada, eastern and northern states), Argentina. The wide distribution of *S. similis* may be due to its apparent association with widespread host(s) on widely distributed grasses such as *Cynodon dactylon.* The presence of *S. similis* in Argentina is considered to be due to human introduction from the northern hemisphere. Similar broad distributions occur in some species of other mymarid genera e.g., *Mymar* spp. (Annecke 1961), *Polynema saga* (Girault) (Ogloblin 1960b). The species has been collected in deciduous and spruce forests in Europe, confirming Debauche's (1948) observations, though most labels did not give a habitat. *Stephanodes similis* must have several generations per year as it has been collected in the northern hemisphere during all months except January and in Argentina in all months except September. Based on material examined to date, the distributions of *S. similis* and *S. reduvioli* appear to be mutually exclusive. In the western hemisphere *S. similis* has not yet been found on the west coast of either North or South America, whereas *S. reduvioli* has not been found in Europe, or the Americas except for the west coast.

Hosts. Unknown.

Material examined. All specimens are on slides unless otherwise stated; the presence or absence of sickle-shaped sensilla on female F3 could not be verified on pointed specimens so their inclusion in *S. similis* is by geographical association only.

ARGENTINA (all specimens in MLPA unless otherwise stated). **Buenos Aires:** Bella Vista, 25.iii.1959, A. Ogloblin (1♀); José C. Paz, 14.i.1939, A. Ogloblin (3♀♀), 1940 (1♀), vi.1940 (1♀), 20.xii.1940 (1♀), no date (1♂, 2♀♀) *Cynodon dactylon*, 2.x.1942 (1♀); La Plata, iv.1932, J.A. Rosas Costa (1♀); Tigre, Puerto Tirol, 9.iv.1947, A. Ogloblin (1♂). **La Rioja**: Gobernador Gordillo, 2.v.1955, A. Ogloblin (1♀). **Misiones:** Loreto, 14.ii.1932, A. Ogloblin (1♀), 19.ii.1932, A. Ogloblin (1♀), 23.ii.1932 (1♀), 12.iii.1934, A. Ogloblin (1♀), 20.vi.1936, A. Ogloblin, *Cynodon dactylon* (1♀); 12.vii.1936, A. Ogloblin, *Cynodon dactylon* (1♀), 25.vii.1936, A. Ogloblin, *Cynodon dactylon* (1♀), 14.xi.1936 (1♀), 15.xi.1936, A. Ogloblin (1♀); **Salta (Dept. Oran):** Rio Pescado 17.v.1955 (1♀); **Santa Fe:** Capital, 20.viii.1951, A. Ogloblin (1♀); Santiago del Estero: Termas de Rio Hondo, 24.iv.1951, A. Ogloblin (1♀, 1♂); **Tucumán:** Tafí del Valle, iv.1985, M.A. Delfino (1♀, IFML).

AUSTRIA. **Lower Austria:** Hundsheim, 12.xi.1954 (6♀♀), 22.xi (3♀♀) and 10.x., am fenster (1♀), and 2.x.1941, W. Soyka (NHMW); Hundsheim, Spitzerberg südseite, 2.xi.1941, Novicky (2♀♀, NHMW), Hundsheim, am fenster aus Heu, vii and 22.vii.1943, W. Soyka (1♀, 1♂, USNM). **Styria:** Paal, 11.vii.1958, *Picea excelsa* [= *abies*], ex. ?*Camptomyia strobi* (1♀ on point, MHNG).

BELGIUM. **Brabant:** Ottignies, 11-18.ix.1982, P. Dessart (1♂ on point, CNCI).

CANADA. **Alberta:** Beauvais Lake Provincial Park, 15.vii.1980 G. Gibson (1♀ on point); George Lake, 53°57'N 114°06'W, 2.vi and 19-28.vi.1980, G. Gibson (2♀♀ on points). **Quebec:** James

Bay hwy. km 256-366, vi.1985, H. Goulet (1♀ on point). **Yukon Territory:** Ross River, 16.vi.-31.viii.1984, S.&J. Peck, aspen-willow river terrace (1♀ on point).

CZECH REPUBLIC. **Bohemia:** Revnice near Prague, viii.1925, A. Ogloblin (1♀, 1♂, MLPA). **Moravia:** Vranov, River Dyje, 13.viii.1991, L. Masner (2♀♀, 1♂ on points, CNCI).

FRANCE. **Côte d'Or:** Esbarres, 16.ix.1957, J. Barbier (1♂ on point, CNCI). **Haute Savoie:** Rumilly, 14.ix.1960, C. Besuchet (1♀ on point, MHNG). **Hérault:** Montpellier, 12-16.ix.1978, J.T. Huber (1♀ on point, CNCI).

GERMANY. **Bavaria:** Erlangen, Kifenwald, no date, Dr. Stammer (1♀, NHMW). **Berlin:** Berlin, Botanical Garden, no date or collector (3♀♀, 2♂♂, USNM).

HUNGARY. Mernye Szama, 17.viii-4.ix.1985, N.D. Springate (1♀ on point, CNCI).

ITALY. **Calabria:** CS, La Sila Larica, 1300m, 23.vi.1988, J.D. Pinto (1♂ on point, CNCI).

POLAND. Sliemiewice, 1941, S. Novicky (1♂, Soyka collection).

RUSSIA [?UKRAINE]. Byekovo [?Berehovo], Podkarp., viii.1925, A. Ogloblin (1♂, MLPA).

SPAIN. **Navarra:** around Alsasua, no date, H. Franz (2♀♀ on points, CNCI). **Segovia**: Puerto Navacerrada, 1400m, 13.iv.1960, C. Besuchet, mousses (1♀ on point, MHNG).

SWEDEN. **Uppland:** Uppasla, Eriksberg, 11-19.vii.1987, F. Ronquist (1♀ on point, CNCI).

SWITZERLAND. **Fribourg:** 4.5 km E. Heitenried, 650m, 16.v.1992, H. Baur (1♀ on point, CNCI). **Genève**: l'Allondon, 7.v.1959, C. Besuchet, tamissage de mousses (1♀, MHNG); Les Tuileries near Chambesy, 21.ii.1962, C. Besuchet, vieille souche (1♀ on point, MHGH); Mategnin, 22.iii.1960, A. Comellini (1♀ on point, MHNG). **Vaud:** Commugny, 24.vi.1956, vitre d'étable, J. Steffen (2♀♀ & 1♂ on points, MHNG); Veytaux, 24.x.1966, bois pourri, C. Besuchet, (1♀, MHNG). **Schaffhausen**: Merishausen, 17.x.1967, feuilles mortes, C. Besuchet (2♀♀, MHNG). **Solothurn:** Richenbach, 560m, 25.viii & 1.ix.1994, P. Flückiger (2♀♀ on points, CNCI). **Valais**: Vouvry, 16.vii.1966, lavage de terre, C. Besuchet, (1♀, MHNG). **Vaud:** Commungny, 24.vi.1956, J. Steffen (1♂ on point, CNCI). **Zurich:** Dielsdorf, 650m, 17.viii.1984 (8♀♀ and 14♂♂ on points, CNCI).

TURKEY. Adana, no date, under *Citrus,* leg. Soylu (11♀♀ & 1♂ on points, MHNG).

UK. England. **Buckhinghamshire:** Burnham Beeches, 1.vi.1908, 24.vi.1908, 23.vii.1908, 13.vii.1910, 26.v.1911, 8.vi.1911, and 24.viii.1911, C. Waterhouse (6♀♀, 4♂♂, BMNH), 2.vi.1908 and 23.vii.1909 (1♀, 1♂, USNM). **Essex:** Epping Forest, Loughton, 18.ix.1908, C. Waterhouse (1♂, BMNH). **Cambridgeshire:** Abbots Ripton, Monks Wood NNR, 17-28.vii.1978, Fitton & Noyes (1♀, BMNH). Scotland. **Strathclyde:** Argyll, Rannoch Moor, 12.vii.1977, Noyes, Rogers & Huddleston (1♀, 2♀♀, BMNH). Wales. **Gwynedd:** Llandudno, 3.viii.1910, 8.viii.1910, C.O. Waterhouse (1♀, 3♀♀, BMNH).

USA. No locality or date (2♀♀ det. as *S. psecas* by Girault, USNM). **Illinois:** Urbana, 25.ii.1945, J.L.C. Rapp (2♀♀, USNM), 22.iv.1909, J.D. Hood (1♀, USNM); Mattoon, 16.viii.1910 A.A. Girault (1♀ and 1♂, USNM). **Iowa:** Ames, 10.x.1943 (1♀, 1♂, USNM, MLPA) 15.x.1943, A. Ogloblin (1♀, MLPA); 17.x.1943, (8♀♀, MLPA); 26.x.1943, Ogloblin (1♀, 2♂♂, MLPA); 3.xi.1943 (1♀ compared with type, MLPA). **Minnesota:** Crookston, 12.ix.1960, A.E. Grable (3♀♀, DEFW); Lansboro, 15.ix.1913 (2♀♀, DEFW). **Missouri:** Williamsville, 12-29.v.1970, J.T. Becker (1♀ on point). **Wisconsin:** Rock Co., T4N,R13E,S25, 1-17.vi.1976 (1♀, UWEM).

YUGOSLAVIA. **Slovenia:** Bled, 5-12.viii.1978, L. Huggert (1♂ on point, CNCI), Rakek, 6.viii.1978, L. Huggert (1♀ and 1♂ on points, CNCI).

Stephanodes reduvioli Perkins
(Figs. 57-59)

Polynema reduvioli Perkins, 1905: 196. References subsequent to the original description are given in Beardsley and Huber (in press).

Polynema (*Stephanodes*) *imbricatus* Narayanan & Subba Rao, 1961: 667. **Syn. n.**

Stephanodes imbricatus; Taguchi, 1978: 75; Subba Rao and Hayat, 1983: 140; Hayat, 1992: 87.
Stephanodes orientalis Taguchi, 1978: 73; Subba Rao and Hayat, 1983: 140. **Syn. n.**
S. similis; Doutt, 1955: 17, misidentification.

Type material. *Stephanodes reduvioli.* Lectotype female (BMNH), examined and here designated, in good condition. Labelled: 1."*Polynema reduvioli.* P. 3♀ 1♂ Hawaiian Is.". 2."R.C.L. Perkins Coll. B.M. 1955-742". Paralectotypes. 2 females and 1 male, on same slide as lectotype. A red label reading: "*Polynema reduvioli* Perkins Lectotype ♀, des. Huber 1997" has been added to the slide. The lectotype is the lower right specimen on the slide.

Perkins did not designate a holotype and did not indicate how many specimens he had examined, though there must have been at least a male and a female. The lectotype slide bears no date. Because it is the only Perkins material of *P. reduvioli* that is slide mounted it is the most appropriate to designate as lectotype because the sickle-shaped sensilla are clearly visible. Additional, potential type material consists of one male and one female specimen (BPBM) from Makaweli P., xi.1905 and 7.xi.1905 (no collector mentioned), though the date may indicate the specimens were collected a little too late to be described and published by Perkins in November, 1905. Finally, the BMNH has four card-mounted specimens on 3 pins that are Perkins material. The date on one specimen is "1906" so we are assuming that none of these specimens is part of the original material.

Stephanodes imbricatus. Holotype female (IARI), not examined. The exact number of paratypes was not mentioned in the original description, but all were collected in 1960.

Stephanodes orientalis. Holotype female (Ehime University, Matsuyama), not examined.

Diagnosis. The presence of a sickle-shaped sensillum on F3 separates most female *S. reduvioli* from *S. similis*. As for *S. similis*, a few specimens of *S. reduvioli* were found to have this sensillum on one antenna only, so the feature is not completely reliable. Specimens with a sensillum on only one antenna may be *S. similis* instead. As for *S. similis*, provenance of the specimens will help determine the species to which they should be assigned.

Descriptive notes. Forewings of the nominal species *S. reduvioli* (from Kaui I., Kokee), *S. orientalis* (from Tsukuba), and *S. imbricatus* (from New Dehli) are illustrated in Figs. 57-59, respectively, and measurements of two populations are given in Table I. Little variation could be found but measurements of specimens from different islands sometimes do not overlap for certain characters, *e.g.*, forewing L/W of specimens from Saipan compared to specimens from the Hawaiian Islands (Table I).

Discussion. Hayat (1992) thought it likely that *S. imbricatus* would be eventually synonymized under *S. similis* but we synonymize this species under *S. reduvioli* instead because of the presence of a sickle-shaped sensillum on F3 on the three topotypical specimens examined.

Distribution. *Stephanodes reduvioli* is widespread in the Oriental, Australian, parts of the Palaearctic regions, and many Pacific islands. Of particular interest are the records from California and Peru, the only ones for the western Hemisphere. Beardsley and Huber (in press) listed collection localities throughout the Hawaiian island chain from Hawaii I. to Kure Atoll. Other records are given below. Its distribution appears to be mutually exclusive to that of *S. similis*.

Material examined. AUSTRALIA. **New South Wales**: Monga State Forest, 700m, 19-24.i.1984, L. Masner (1♂ on point, CNCI); Clyde Mountain, 1000m, 21.i.1984, L. Masner, lush ferns in Eucalyptus forest (4♀♀ and 1♂, on slides, 29♀♀ and 1♂ on points, 7♀♀ used for SEM, CNCI). **Northern Territory**: 58 km SE. Adelaide River, 28.iii.1991, J.D. Pinto (1♀, CNCI). **Queensland:** 41 km N. Charleville, Warrego River, 16.v.1991, E.C. Dahms, G. Sarnes (1♀, QMBA); Yeerongpilly, 1-10.i.1982, B. Cantrell (4♀♀, QDPI). **South Australia:** Fleurieu Peninsula, Deep Creek Conservation Park, 25.xi.1989 & 10-24.xii.1989, R. Wharton (3♀♀ on points, TAMU). **Victoria**: The Grampians, Rose's Gap, 17-21.xii.1989, R. Wharton (1♂, TAMU). **West Australia:** 10 km N. Kununurra, 25-

29.iii.1991, G. Gordh & J.D. Pinto (1♀ on point, CNCI); The Grotto, 25 km S. Wyndham, 26.iii.1991, J.D. Pinto (1♀ on point, CNCI).

ECUADOR: **Galapagos Is.**: Santa Cruz I., Bellavista, agriculture zone, 160m, 1-9.iv.1989, S. Peck & B. Sinclair (1♀, CNCI).

FIJI. **Viti Levu:** Nandarivatu, 1100m, microwave station, 16-23.viii.1978, S. & J. Peck (1♀ on point, CNCI).

FRENCH POLYNESIA. **Bora Bora:** 1 km E. Faanvi, 5.ix.1984, D.M. LaSalle (1♀ & 1♂ on points, CNCI). **Moorea**: Haapiti, marker 16 on highway, 1.ix.1984, D.M. LaSalle (1♂, CNCI); Roto Nui, 31.viii.1984, D.M. LaSalle (3♀♀ & 2♂♂, CNCI). **Tahiti:** Maeva Beach, 8.ix.1984, D.M. LaSalle (2♀♀ & 1♂ on points, CNCI).

INDIA. **Delhi Territory**: Delhi, 11.v.1957 (1♀, IARI) and iii.1962, B. Subba Rao, on lucerne (2♀♀, CISC).

IRAN. **Central Province**: Karaj, 16-22.vii.1978, J.T. Huber (1♀, CNCI); Shahdasht, 5.vi.1978, J.T. Huber (1♀, CNCI).

JAPAN. Honshu. **Ibaraki Prefecture**: Tsukuba, NAIES, 31.v-8.vii and 26.vi-10.vii.1989, M.J. Sharkey (1♂, CNCI).

NEW ZEALAND. **BP**: Mamaku Plateau, Galaxy road, 27 km W. Rotorua, 6-11.iii.1978, S.& J. Peck (1♀, BMNH). **OL:** Makarora, 21-24.i.1978, S. & J. Peck (1♀ on point, CNCI).

NORTHERN HAWAIIAN ISLANDS. **Kure Atoll**: ix.1961, G.D. Butler (6♀♀, CISC).

NORTHERN MARIANA ISLANDS. **Saipan**: no locality and Chalan Kanoa, 11.xi.1948, R.L. Doutt, sweeping grass (19♀♀, CISC).

PERU: **Lima**: Chosica, 16.xii.1983, A. Finnamore (1♀, CNCI).

USA: **California**: Shasta Co., Castello, 26.vi.1954, R.O. Shuster & B.J. Adelson (1♀, CISC).

Stephanodes polynemoides (Yoshimoto)
(Figs. 7-12, 19-24, 29-32, 36-38, 54)

Masonana polynemoides Yoshimoto 1990: 100.

Type material. Holotype (CNCI), examined. Point-mounted, in good condition except right hindwing missing, and left antenna and forewing mounted in Canada balsam on slide. The type label gives the altitude of the type locality as 1700m (not recorded in the original description).

Diagnosis. The forewing (Fig. 54) has two very dark apical spots and a single broad band beyond the venation. These features easily characterize this species. The size of the apical spots varies considerably. Two specimens from Guatemala have very small spots, whereas most other specimens have larger spots and, in particular, the anterior spot may vary from being almost circular to kidney-shaped. We consider all these variants to represent intraspecific variation.

Distribution. The species extends from Ecuador to Central Mexico and has been collected mainly above 1500m, though one specimen was collected at 700m.

Material examined. The following records are in addition to the type material listed by Yoshimoto (1990).

COSTA RICA. **Alajuela:** Penas Blancas, 700m, 18.viii.1986, L. Masner, rainforest (1♂, CNCI). **San José:** Zurquí de Moravia, 1600m, v.1995, P. Hanson (1♂, CNCI).

GUATEMALA. **Zacapa:** above San Lorenzo, 2200m, xi.1986, M. Sharkey (1♀, CNCI). **Sacatepequez:** Volcán Agua, 1700, above Antigua Guatemala, 23.xi.1986, M. Sharkey (1♀, CNCI).

Stephanodes missionicus (Ogloblin)
(Fig. 60)

Eustephanodes missionicus Ogloblin, 1967: 194.
Stephanodes missionicus; Yoshimoto, 1990: 72.

Type material. Holotype ♀ (MLPA), examined. This species was described from two females from Aristóbulo del Valle, Missiones, collected on 28.xi.1960 and 15.xi.1962. Three specimens (on three slides) in the MLPA collection belong to this species but only one slide bears one of these dates (28.xi.1960). The specimen on this slide is treated here as the holotype and is labelled accordingly. The second specimen is either missing, or else Ogloblin simply misrecorded the date and it is on one of the two other slides in MPLA. These have the following data: Aristóbulo del Valle, xi.1963 and Dos de Mayo, 12.xii.1965. The first slide bears only wings and antennae but the second has a complete specimen.

Diagnosis. *Stephanodes missionicus* is most similar to *S. septentrionalis*, from which it is distinguished by its mostly yellow female funicle, and its very slender body and relatively long appendages. Measurements are given in Table I.

Distribution. Argentina.

Stephanodes chestertoni (Debauche)

Polynema chestertoni Debauche, 1949: 67.
Stephanodes chestertoni; Mathot, 1968: 275; Taguchi, 1978: 75.

Type material. Holotype ♀, not examined. This species is not included in the key because we were unable to examine the types, the only material of this species known, and the original description provides no reliable indication on how to differentiate the species from other *Stephanodes* species. Apparently the types were never returned to the Musée Royal de l'Afrique Central, Tervuren (E. Deconinck, pers. comm.).

Stephanodes septentrionalis Huber sp. n.
(Figs. 1-6, 13-18, 25-28, 33-35, 39-42, 43-46, 53, Table I)

Diagnosis. Forewing (Fig. 53) relatively larger (wider and longer) than *S. similis* or *S. reduvioli* and with a faint but distinct dark band formed apparently by darkened setae a little beyond apex of venation (without band or rarely with faint suffusion in the other species except *S. polynemoides*). The petiole is about the same length in *S. septentrionalis* and *S. missionicus*, but relatively longer than in the other clear-winged species. Thus, on wing and petiole measurements, *S. septentrionalis* appears to be most similar to *S. missionicus*, but the latter lacks the darker band on the forewing and has a longer marginal space (area devoid of microtrichia on dorsal wing surface just beyond venation) than *S. septentrionalis*. The new species occurs sympatrically with *S. similis*, *e.g.*, both species were collected at the same time and place at George Lake, Alberta.

Type Material. HOLOTYPE ♀ (CNCI), on slide under 4 coverslips and labelled 1."ON: Aylmer, 8.ix.1978, L. Masner, G. Gibson, H. Goulet, primary forest, sweeping." 2."Stephanodes septentrionalis Huber HOLOTYPE ♀ dorsal". The type locality is actually the Springwater Conservation Area, 6 mi. W. Alymer (H. Goulet and L. Masner, pers. comm.), as for some of the paratypes.

PARATYPES (CNCI, USNM, BMNH, UCRC). 25♀♀ and 14♂♂ on points or cards, 3♀♀ and 10♂♂ on slides. The bodies of 4 specimens were used for SEM, and their wings are on a slide. The specimens were collected by screen sweeping, Malaise traps and pan traps. CANADA. **Alberta:** 20

mi. W. Legal, George Lake, 31.v-3.vi.1978, D.R. Smith (1♀, USNM); 0.5 km E. Writing-on-Stone Provincial Park, 15-22.vi.1981, D. McCorquodale (1♂). **British Columbia:** Blind Bay, Shuswap Lake, 1-15 and 15-31.viii.1986, C.A. Elsey (18♂♂); Sorrento, 17-20.vii.1991, H. Goulet, weedy garden (1♀, 3♂♂, wings only, rest of body for SEM). **New Brunswick:** Fundy National Park, Wolfe Point campground, 27.viii.1984, M. Kaulbars (2♀♀); Kouchibouguac National Park, 31.v.1977, S.J. Miller (1♀). **Nova Scotia:** Cape Breton Highlands National Park, 46°85'N 60°26'W, 22.vi.1983, barrens (1♀). **Ontario:** Aylmer, 8.ix.1978, L. Masner, G. Gibson, H. Goulet, primary forest (6♀♀); Innisville, 25.vii.1963 (1♂); Milton, 8.ix.1981, M. Sanborne (3♀♀); Lake Louisa, Algonquin Park, 17.v.1980, S. & S. Miller, sweeping hardwoods (1♀); Springwater Conservation Area, 6 mi. W. Aylmer, 28.v-4.vi.1979, L. Masner, (1♀); St. Lawrence Is. National Park, Grenadier I. central, 16.vii.1975, ex. *Quercus rubra*, E. Sigler (1♀); Wylde Lake bog, 8 km E. Arthur, 15-23.v 1987, S.A. Marshall, lake edge and floating mat (2♀♀) and 8-15.vi.1987, floating mat, D. Blades (1♀). **Quebec:** James Bay highway, km 129, 10-18.vi.1985, H. Goulet & D.R. Smith (2♀♀, USNM) and km 256-366, vi.1985, H. Goulet (1♀).

USA. **New Hampshire:** 5.6 km S. Gorham, hwy. 16, 9.ix.1987, A. Smetana (2♀♀). **Pennsylvania:** Cambia Co.: 3 km N. Wilmore, 650m, 30.v.1991, L. Masner (1♀). **Washington:** Ashford, W. Mt. Rainier National Park, 1-14.viii.1985, L. Masner (1♀). **Wisconsin:** Bayfield Co.: T46N R9W,S16, 31.viii-8.ix.1976 (1♂, UWEM).

Distribution. Canada, Northern United States.

Biology. Host unknown. The species was collected in various, mostly natural, habitats including a primary forest (Aylmer, ON), a weedy residential garden (Sorrento, BC), a bog (Wylde Lake, ON), and rocky barrens (Cape Breton Highlands Nat. Park, NS). It is mainly a northern species, to date found only as far south as Pennsylvania.

Species name. Latin for north, referring to its more northerly distribution relative to the other western hemisphere species of *Stephanodes*.

Species check list, geographical distribution and abundance.

Stephanodes is a worldwide genus, occurring on all five continents and many oceanic islands. Ten nominal species have been described to date. Previous synonymy reduced this to seven and we further reduce this to five. In the list below, synonyms and replacement names are indented under the next most senior synonym, and the original generic placement is given in parentheses. The region from which each nominal species was first described is also given.

*S. similis (*Förster) (*Polynema*). Germany.
    S. isotoma Debauche (*Polynema*), replacement name.
    S. elegans Enock. England.
    S. enockii (Girault) (*Polynema*), replacement name.
    S. psecas Girault. USA. **Syn. n.**
S. missionicus Ogloblin (*Eustephanodes*). Argentina.
S. chesteroni (Debauche) (*Polynema*). Zaire.
S. reduvioli (Perkins) (*Polynema*). Hawai'i.
    S. imbricatus Narayanan & Subba Rao (*Polynema*). India. **Syn. n.**
        S. ahlaensis Mani & Saraswat (1973) (*Polynema*). India.
    S. orientalis Taguchi. Japan, Taiwan. **Syn. n.**
S. polynemoides (Yoshimoto) (*Masonana*). Costa Rica, Ecuador, Venezuela, Panama. **Comb. n.**

Territories (and islands within territories) from which material has been examined but not necessarily identified to species are listed below. The specimens are in the CNCI unless otherwise noted. Undoubtedly more countries could be added from specimens in collections not yet examined. Such specimens may be misidentified as *Polynema.* Taiwan, which has a *Stephanodes* recorded from it in the literature, but for which voucher specimens were not seen by us, is included followed by the literature reference.

Nearctic: Canada, United States.

Neotropical: Argentina, Bolivia, Chile (UCD), Costa Rica, Dominica (USNM), Ecuador (Galapagos Is.), Guatemala, Mexico, Netherlands Antilles, Panama, Peru, Venezuela.

Palaearctic: Belgium, Czech Republic, France, Germany (BMNH), Italy, Hungary, Japan (Honshu, Kyushu, Shikoku) Spain, Sweden (MZLU), Switzerland, UK (BMNM), Yugoslavia, Iran, Nepal.

Afrotropical: Botswana, Ethiopia, Ivory Coast, Malawi, Mauritius (BMNH), Nigeria, Sierra Leone (MZLU), South Africa (BMNH, MZLU), Sudan (BMNH), Zaire, Zambia.

Oriental: India (CISC, IARI), Pakistan, Philippines (Luzon I.) (BMNH), Taiwan (Taguchi 1978).

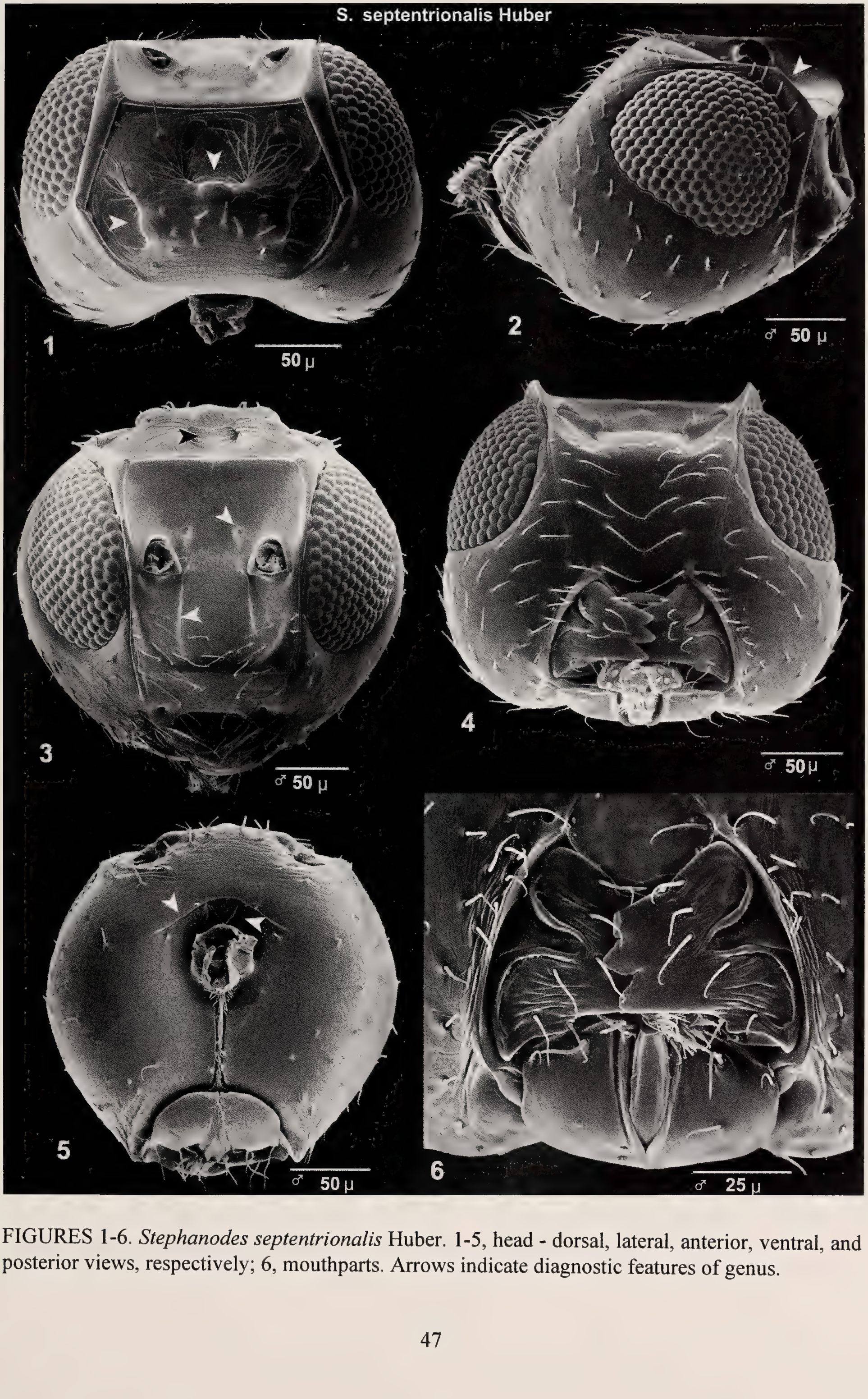
Australian and Pacific: Australia, Fiji (Viti Levu I.), Hawai'i (Kauai I., Kure Atoll, Molokai I., Pearl & Hermes Atoll, Laysan I., Oahu I.), Midway I., Northern Mariana Is. (Saipan) (CISC), Society Islands (Tahiti, Moorea, Bora Bora).

A collection of about 600 specimens of *Polynema* received for identification from a gypsy moth survey using Malaise traps in Minnesota included six *Stephanodes.* On the basis of this single sample *Stephanodes* appears to be about 1% as abundant as *Polynema.* Because of similarity in colour and habitus, collections of *Polynema* should be examined carefully for the occasional *Stephanodes* that is likely to be included with them.

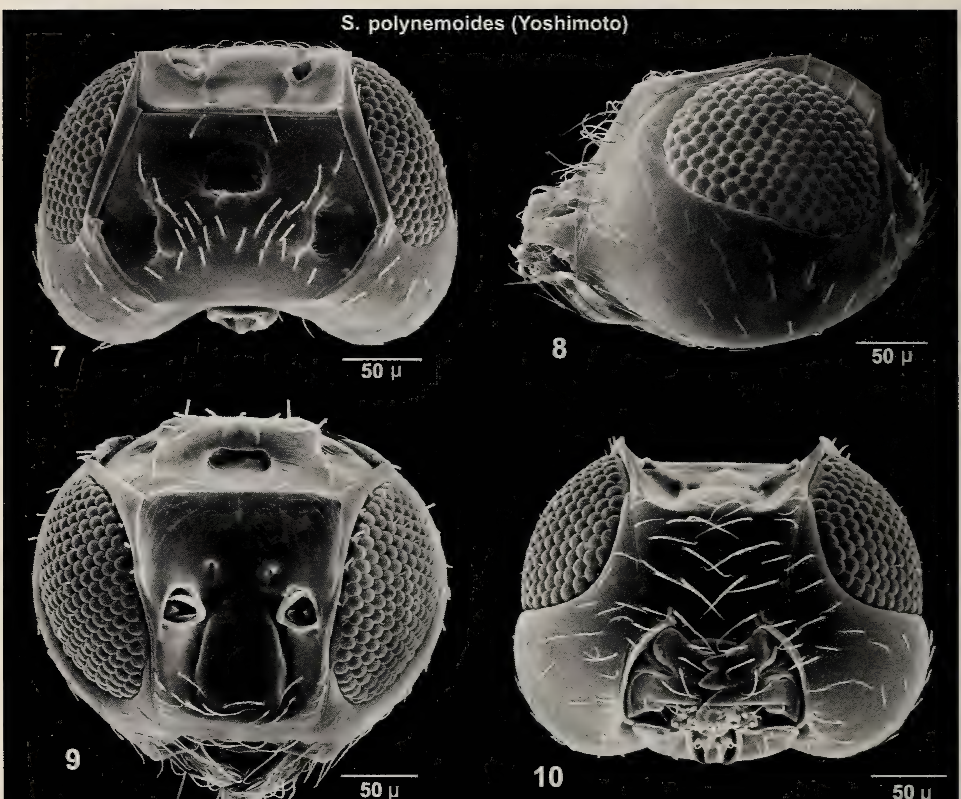
Discussion

Two lines of evidence suggest that the genus *Stephanodes* originated in the New World, likely in South America. First, the presumed sister group *Agalmopolynema* is only known from southern South America. Second, the greatest morphological diversity and perhaps also number of *Stephanodes* species (five) occurs in the New World, though we consider two of these, *S. reduvioli* and *S. similis*, as introductions from the Old World. The next most diverse region is perhaps Africa, with at least 3 species of which only one, *S. chestertoni*, is described. The rest of the world has two widespread species that are extremely similar morphologically, though perhaps several others, similar to *S. similis* or *S. reduvioli*, exist.

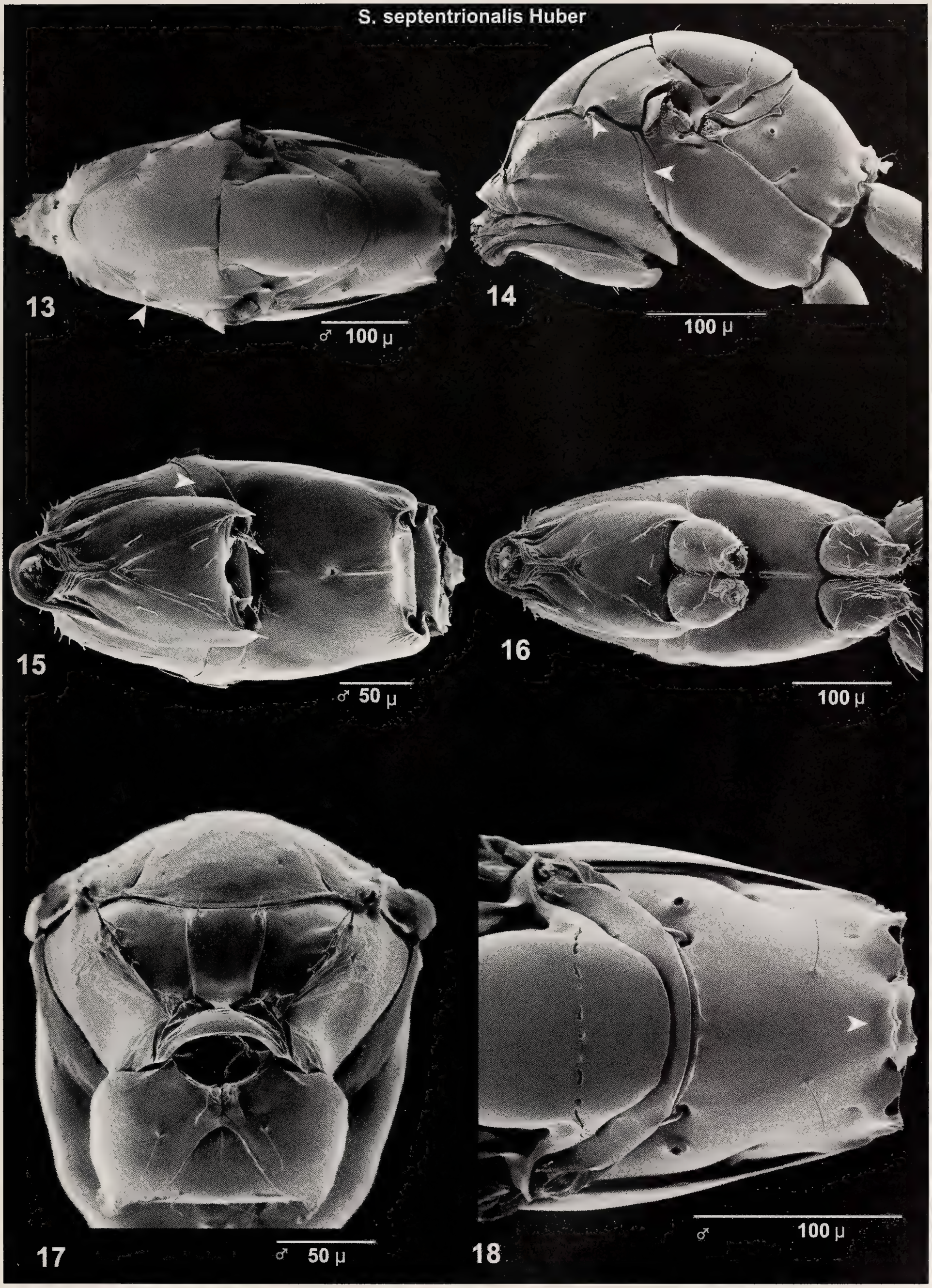
Within the *S. similis/reduvioli* nominal species, two extremes of speciation can be envisaged. First, populations of *Stephanodes* in each reasonably cohesive region, *e.g.*, Europe, Indian subcontinent, southeast Asia, Africa south of the Sahara, Japan, Australia, and the various Pacific Islands, could each represent a different species, perhaps differentiated by minute morphological differences as well as biological differences. Second, there really may be only one or two very widely distributed species with only minor morphological differences among the different regional populations. We have been fairly conservative and have chosen the second alternative, maintaining only two species on the basis of presence or absence of a sickle-shaped sensillum on F3. More biological information, particularly cross-breeding work, may eventually demonstrate that *S. similis* and *S. reduvioli* actually represent only one species.



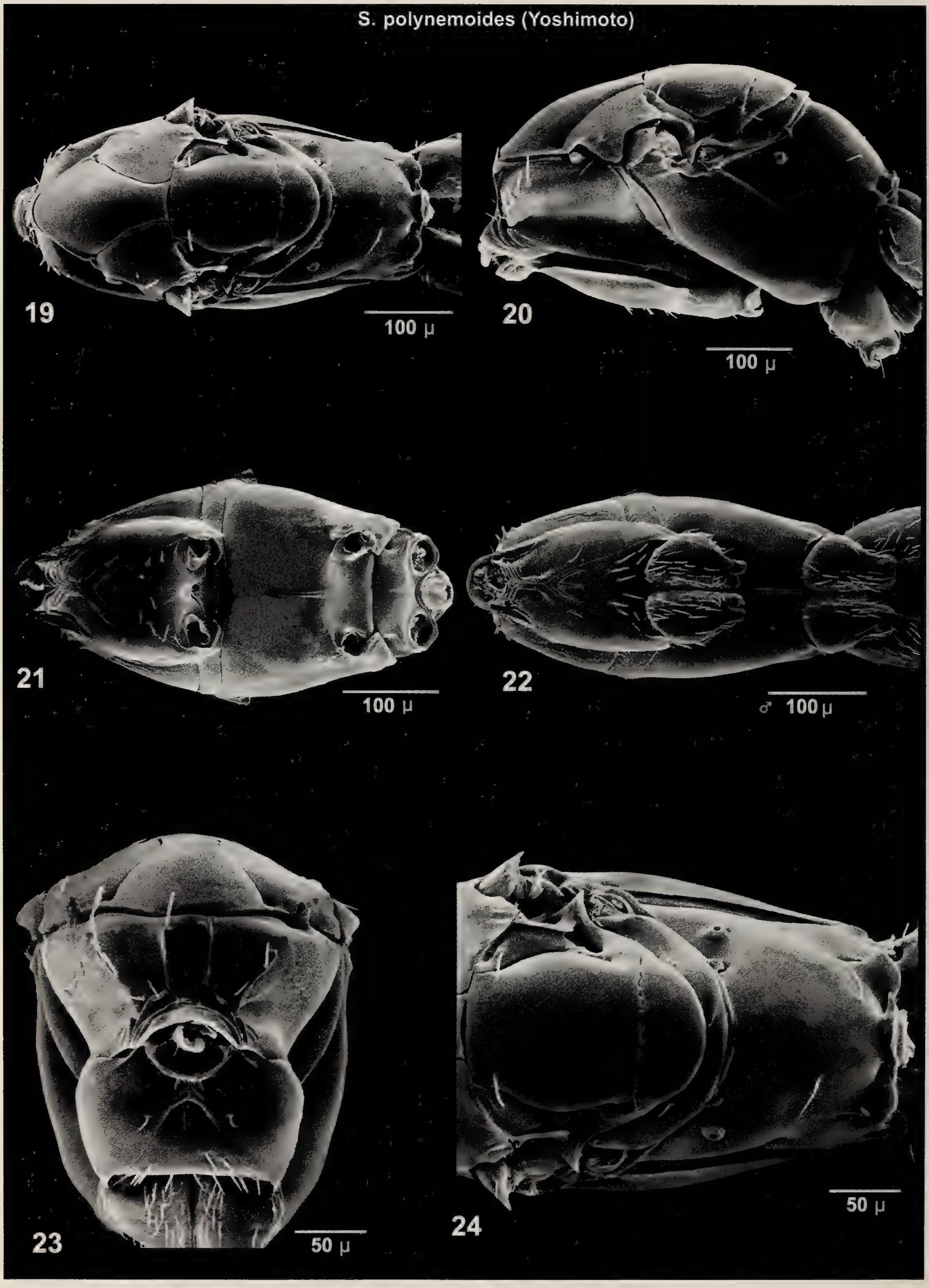
FIGURES 1-6. *Stephanodes septentrionalis* Huber. 1-5, head - dorsal, lateral, anterior, ventral, and posterior views, respectively; 6, mouthparts. Arrows indicate diagnostic features of genus.



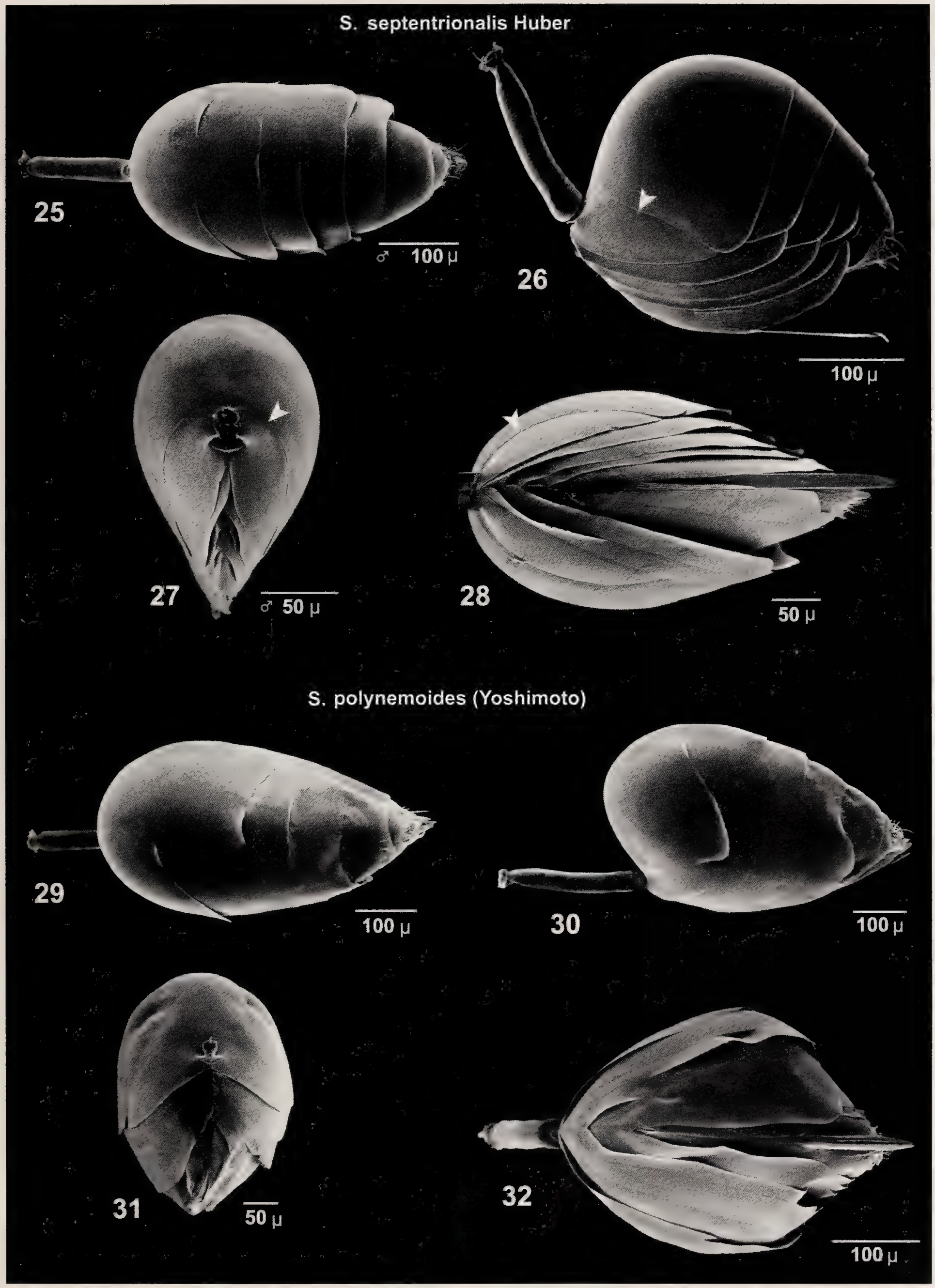
FIGURES 7-12. *Stephanodes polynemoides* (Yoshimoto). 7-11, head - dorsal, lateral, anterior, ventral, and posterior views, respectively; 12, mouthparts.



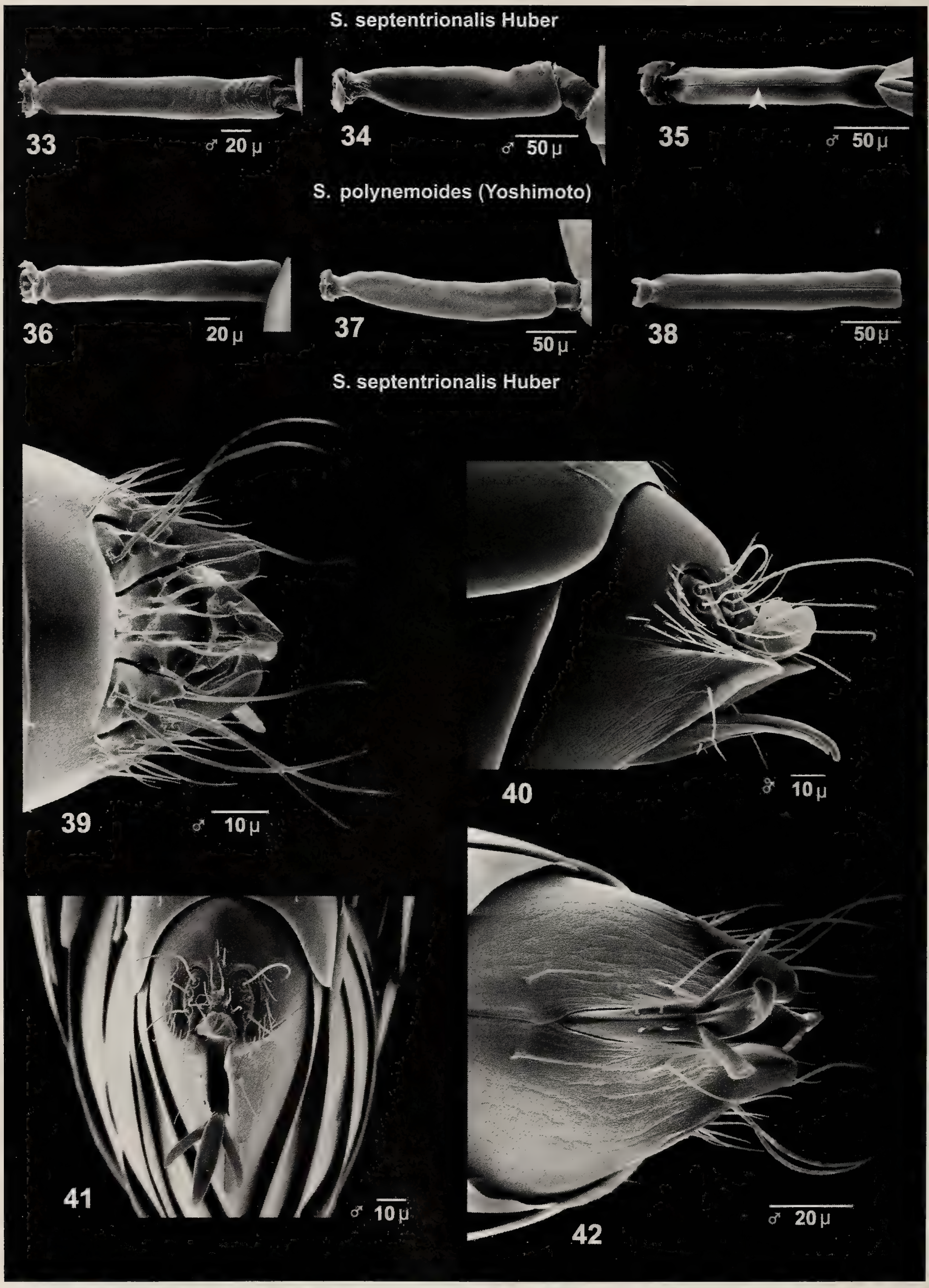
FIGURES 13-18. *Stephanodes septentrionalis*. 13-17, mesosoma - dorsal, lateral, ventral (without and with coxae), and anterior views, respectively; 18, mesoscutum - propodeum. Arrows indicate diagnostic features of genus.



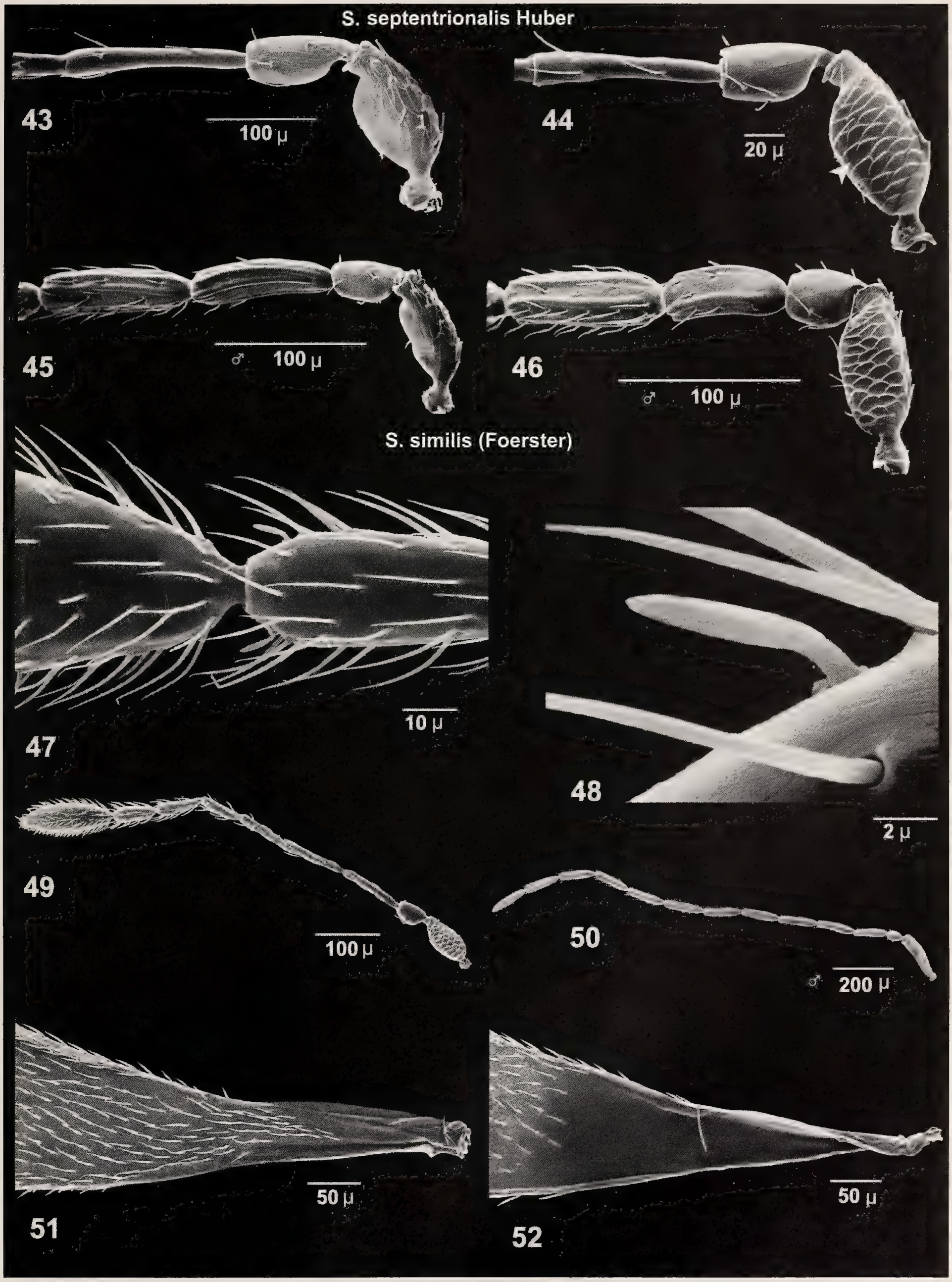
FIGURES 19-24. *Stephanodes polynemoides*. 19-23, mesosoma - dorsal, lateral, ventral (without and with coxae), and anterior views, respectively. 24, mesoscutum - propodeum.



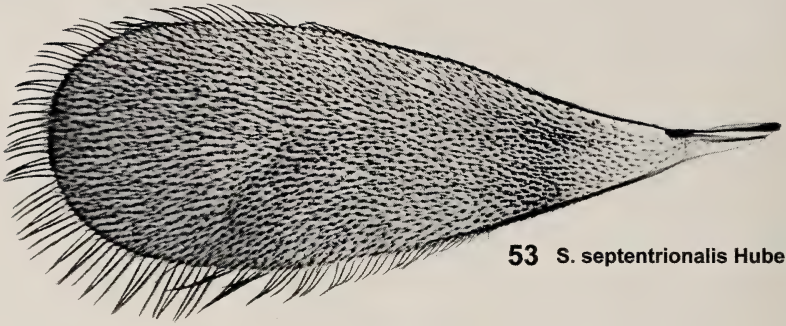
FIGURES 25-32. Metasoma - dorsal, lateral, anterior, and ventral views, respectively. 25-28, *Stephanodes septentrionalis*; 29-32, *S. polynemoides*.



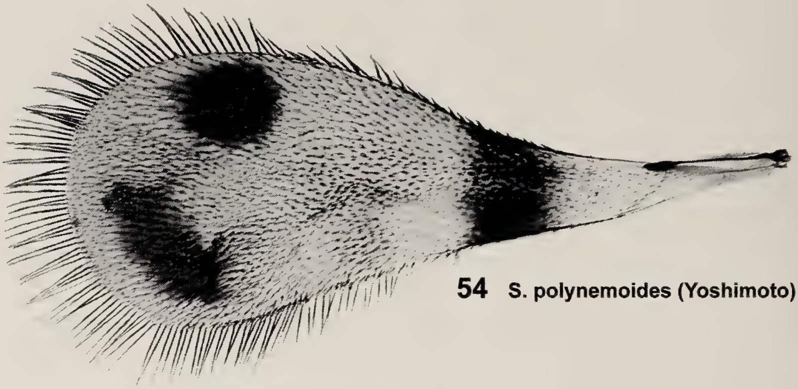
FIGURES 33-42. 33-38, gastral petiole, dorsal, lateral, ventral views, respectively. 33-35, *Stephanodes septentrionalis*; 36-38, *S. polynemoides*. 39-42. *S. septentrionalis*, apex of gaster (and partially protruded male genitalia), dorsal, lateral, posterior, and ventral views, respectively.



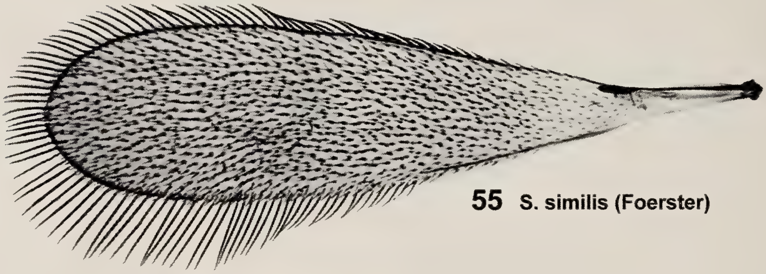
FIGURES 43-52. 43-46, *Stephanodes septentrionalis*, outer and inner aspect of female and male antenna (scape - F1 or, for males, F2), respectively. 47-52, *S. similis* Förster; 47, F6 and base of clava; 48, enlarged sickle-shaped sensillum on funicle segment; 49, female antenna; 50, male antenna; 51, base of forewing, dorsal view; 52, base of forewing, ventral view.



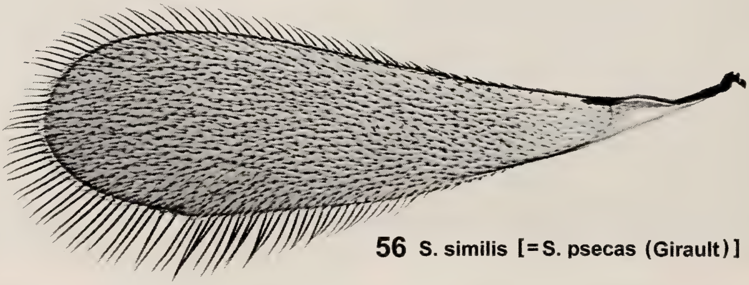
53 S. septentrionalis Huber



54 S. polynemoides (Yoshimoto)

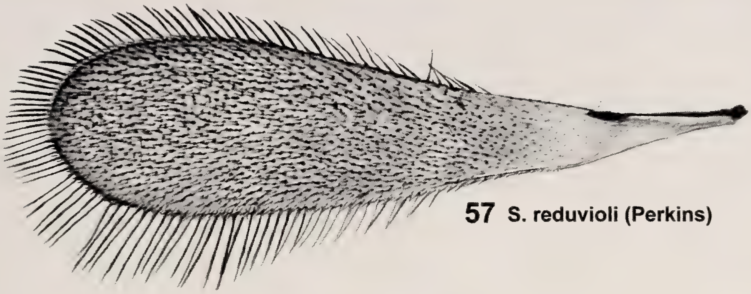


55 S. similis (Foerster)

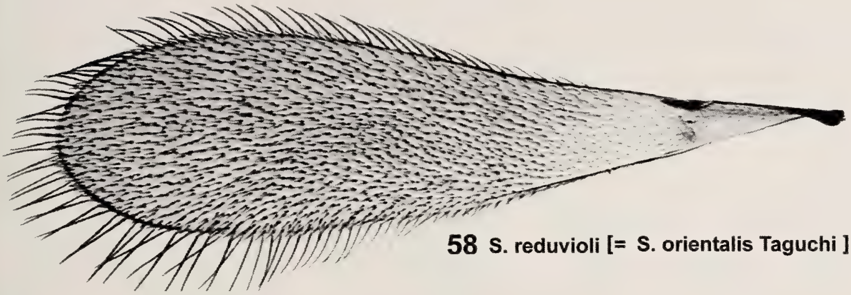


56 S. similis [=S. psecas (Girault)]

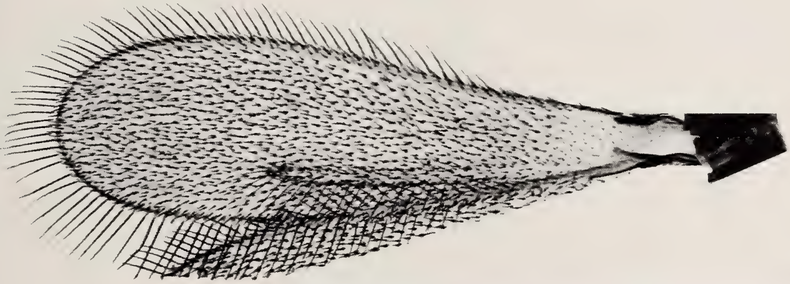
FIGURES 53-56. *Stephanodes* forewings. 53, *septentrionalis*, holotype; 54, *polynemoides*, paratype; 55, *similis* from Vranov, Czech Republic; 56, similis [=*psecas*] from Rock Co., WI, USA.



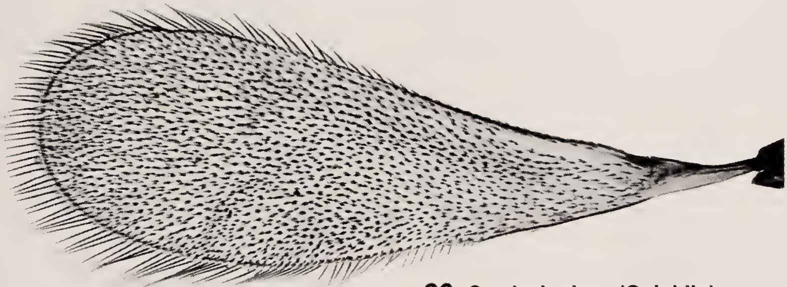
57 S. reduvioli (Perkins)



58 S. reduvioli [= S. orientalis Taguchi]

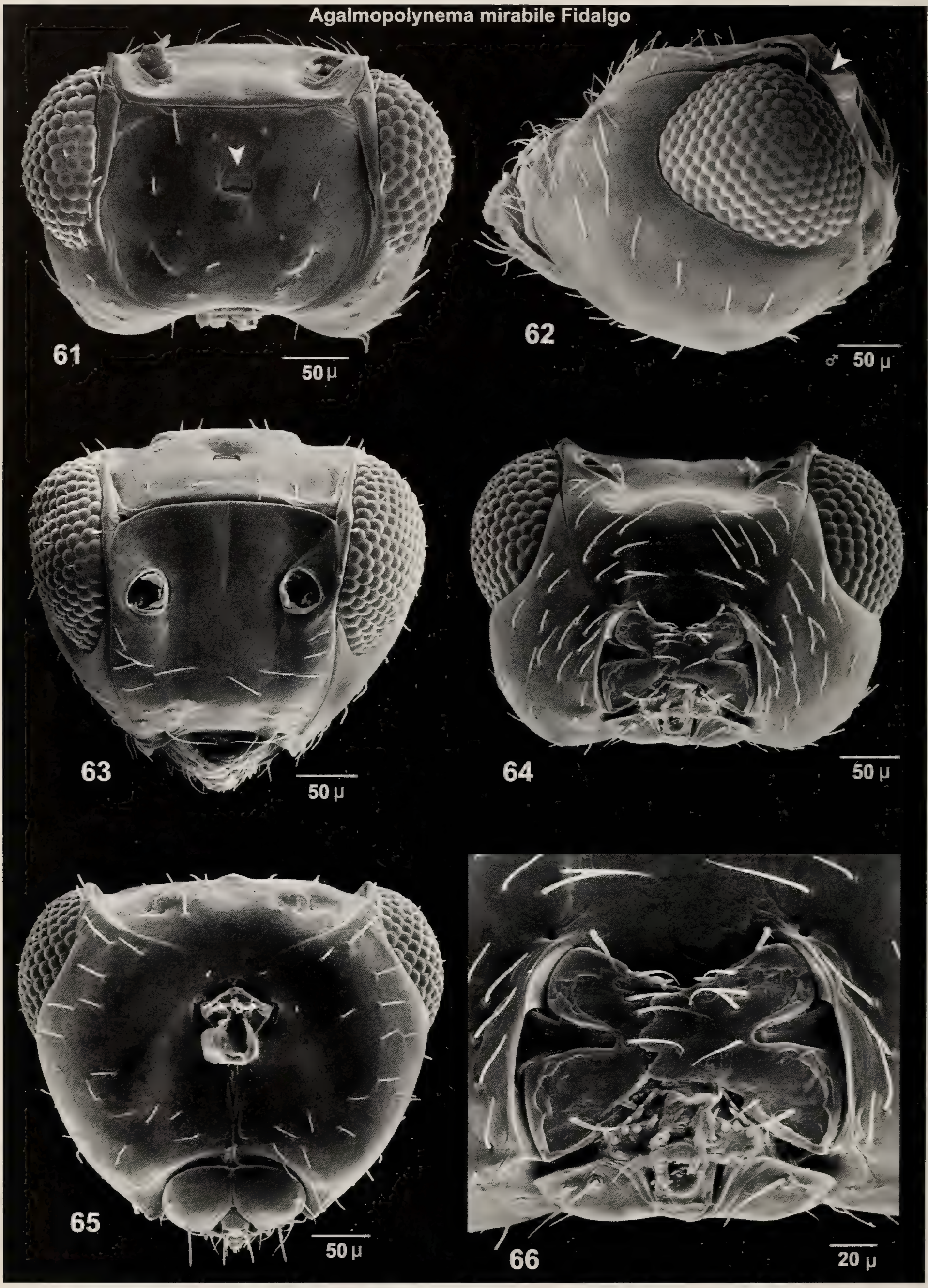


59 S. reduvioli [= S. imbricatus (Narayanan & Subba Rao)]

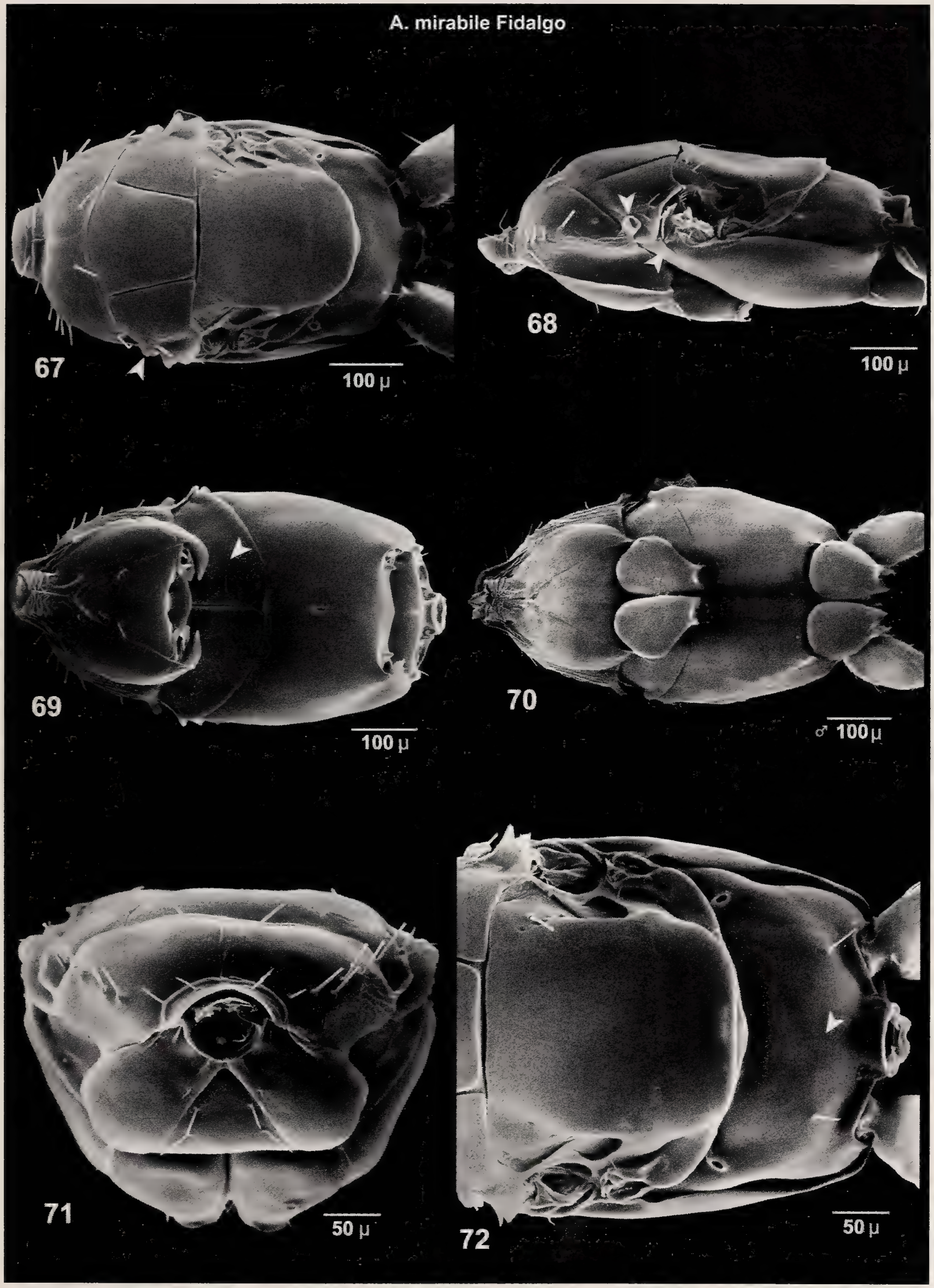


60 S. missionicus (Ogloblin)

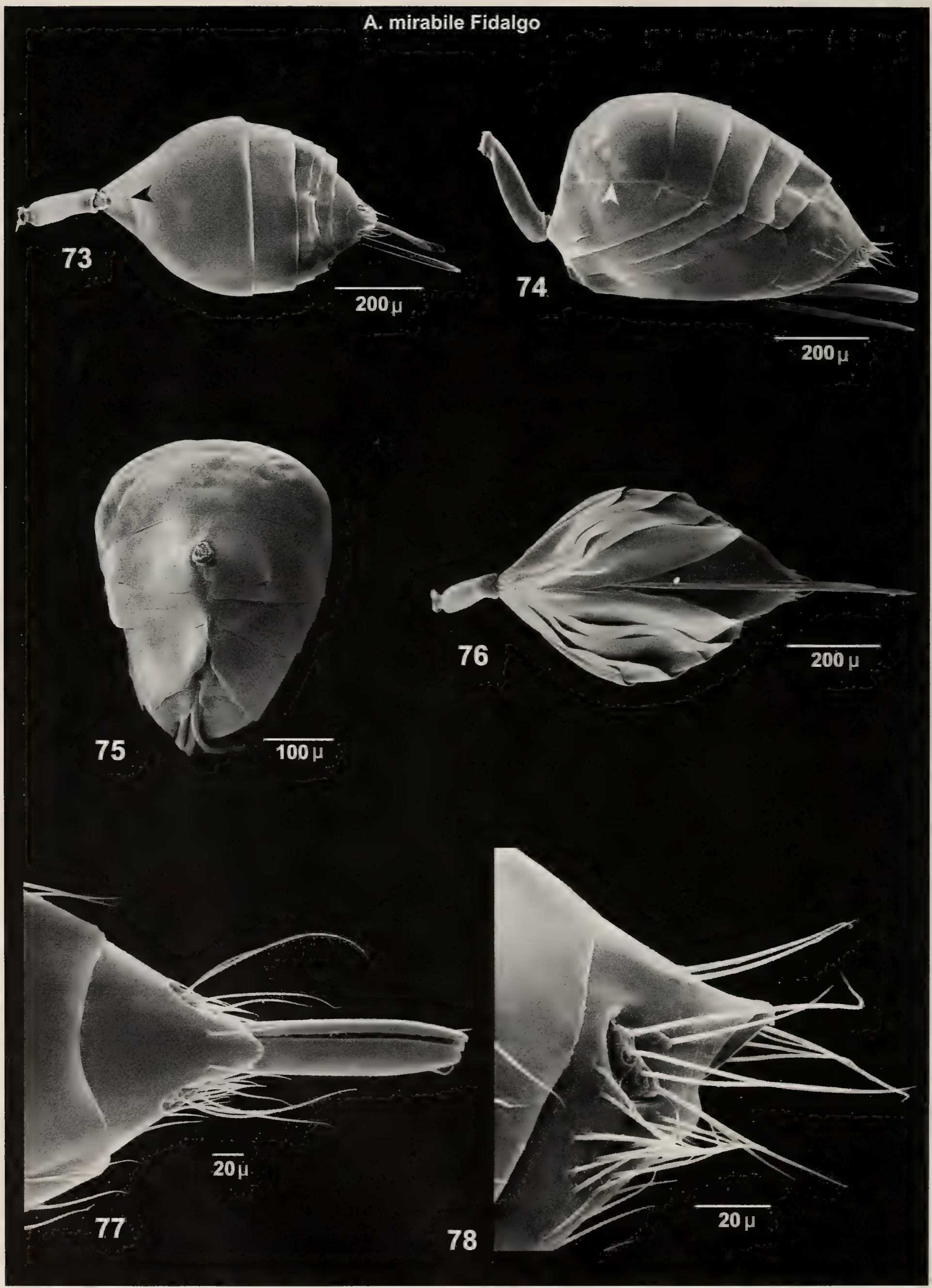
FIGURES 57-60. *Stephanodes* forewings. 57, *reduvioli* from Kokee, Kauai; 58, *reduvioli* [= *orientalis*] from Tsukuba, Japan; 59, *reduvioli* [= *imbricatus*] from New Dehli, India; 60, *missionicus*, paratype.



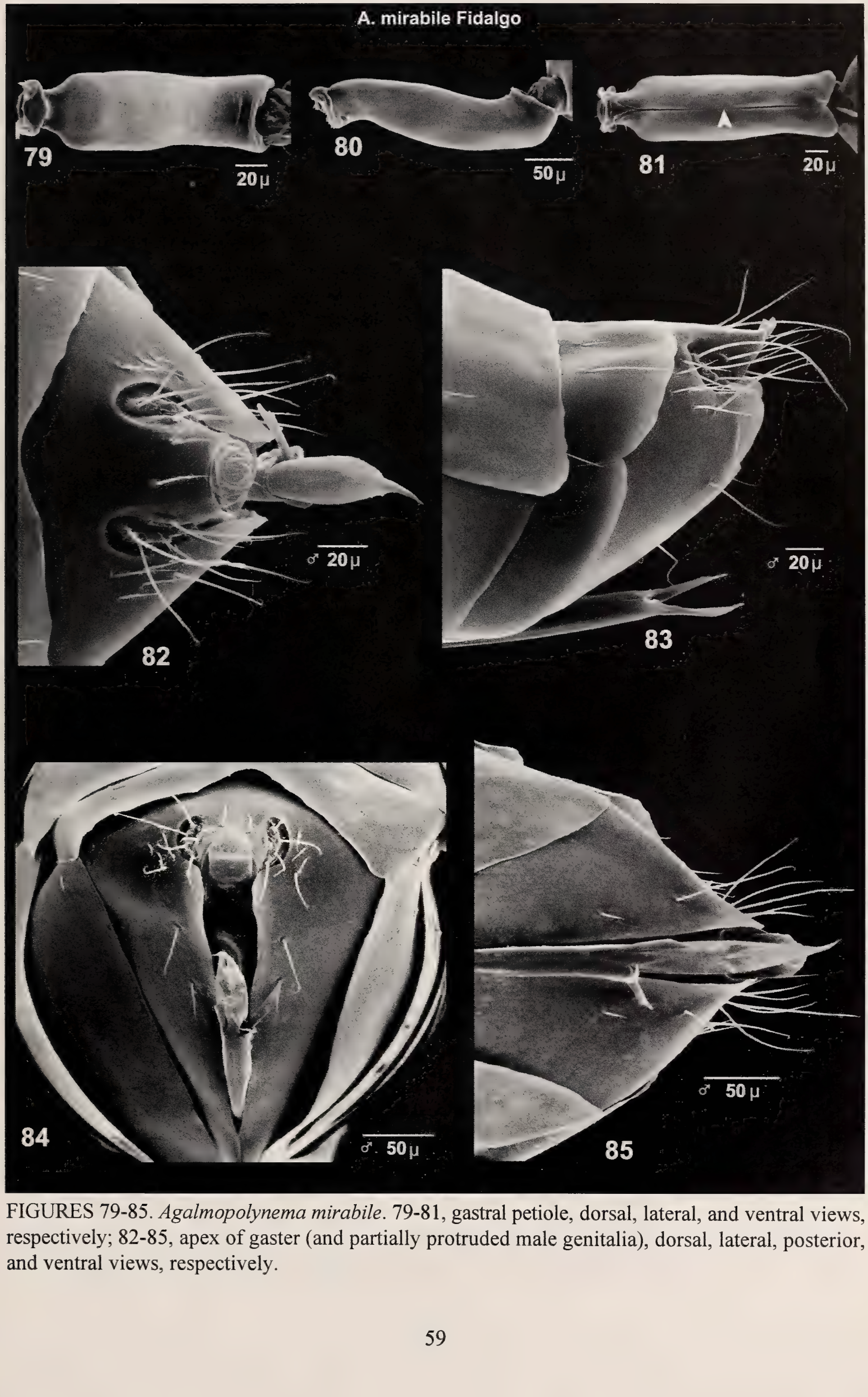
FIGURES 61-66. *Agalmopolynema mirabile* Fidalgo. 61-65, head - dorsal, lateral, anterior, ventral, and posterior views, respectively; 66, mouthparts. Arrows indicate diagnostic features of genus.



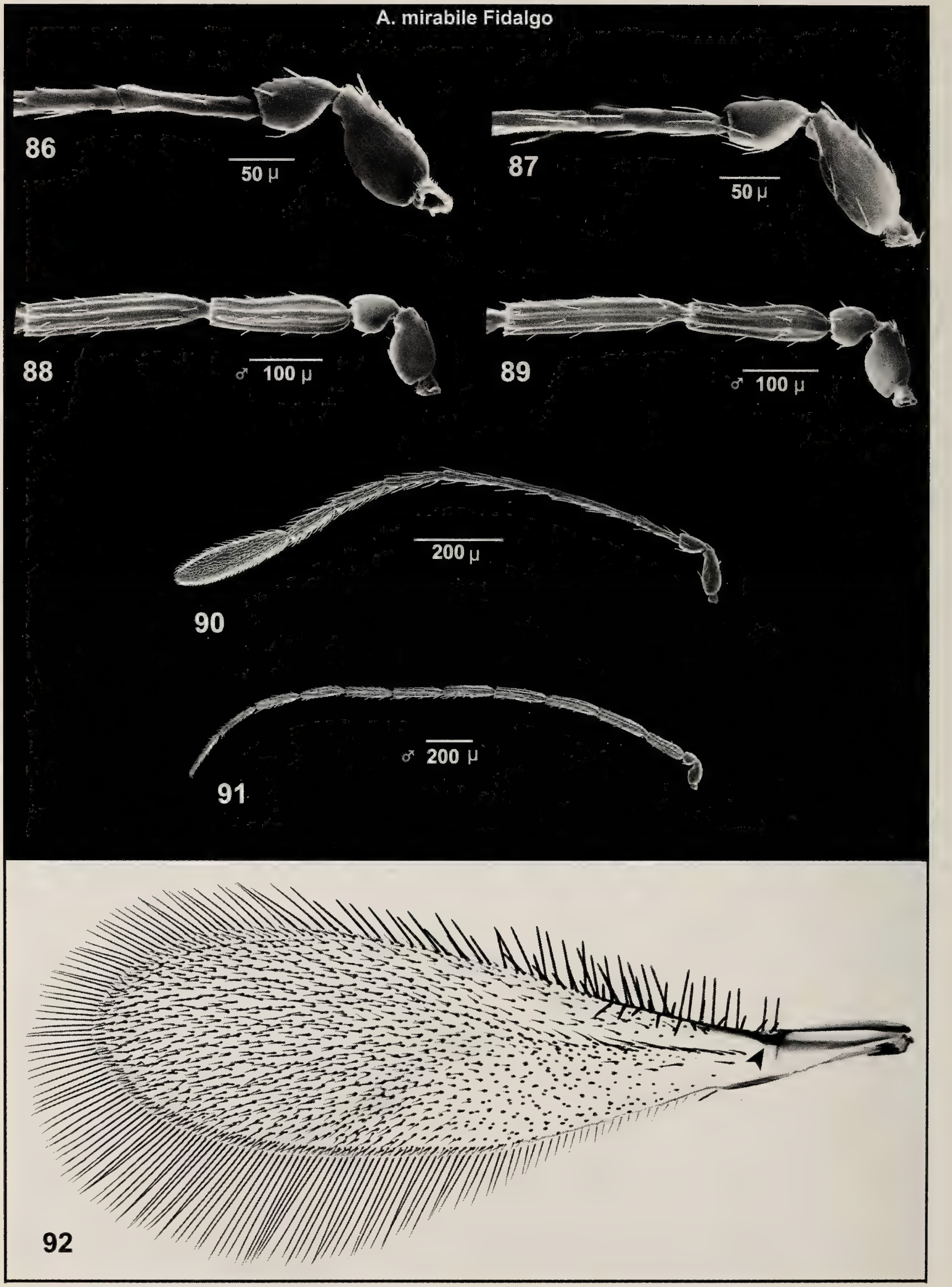
FIGURES 67-72. *Agalmopolynema mirabile*. 67-71, mesosoma - dorsal, lateral, ventral (without and with coxae), and anterior views, respectively; 72, mesoscutum - propodeum. Arrows indicate diagnostic features of genus.



FIGURES 73-78. *Agalmopolynema mirabile*. 73-76, metasoma - dorsal, lateral, anterior, and ventral views, respectively; 77 and 78, apex of gaster, dorsal and lateral views, respectively.



FIGURES 79-85. *Agalmopolynema mirabile*. 79-81, gastral petiole, dorsal, lateral, and ventral views, respectively; 82-85, apex of gaster (and partially protruded male genitalia), dorsal, lateral, posterior, and ventral views, respectively.



FIGURES 86-92. *Agalmopolynema mirabile.* 86-89, outer and inner aspect of female and male antenna (scape - F1 or, for males, F2), respectively; 90, female antenna; 91, male antenna; 92, forewing.

Acknowledgements

Curators of the various museums listed above are thanked for loan of material, particularly the types. Mr. K. Bolte, Canadian Forest Service, Ottawa, prepared the SEM and wing illustrations and assembled the final, digitized computer plates. Drs. G. Gibson and H. Goulet, ECORC, Agriculture Canada, Ottawa, reviewed the final ms and provided valuable suggestions for its improvement.

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USE OF POISSON REGRESSION FOR MODELING HOST SELECTION BEHAVIOR OF THE WESTERN CONIFER SEED BUG, *LEPTOGLOSSUS OCCIDENTALIS* HEIDEMANN (HEMIPTERA: COREIDAE)

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Abstract

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Analysis of variance (ANOVA) is employed in many biological contexts to determine the significance of treatments used. This is justified by appealing to the central limit theorem, which states that for large enough samples, test statistics, such as the mean, are approximately normally distributed, regardless of the distribution that generated the original data. In some areas of biology, particularly ecology and entomology, analyses which rely on the central limit theorem are inferior choices when an appropriately constructed theoretical model can reveal the distribution from which the data were drawn, and test procedures based on the generating distribution are available. An example in which this is the case is the host selection behavior of the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae). We propose that the attraction of *L. occidentalis* to host trees is related to the characteristics of the tree. We show that such a selection procedure implies that insect counts on individual trees are draws from a Poisson distribution. Poisson regression is used to test the hypothesis that tree characteristics contribute to the probability of a tree being chosen by *L. occidentalis* and to determine which specific variables are significant in the model. We conclude that when the theoretical framework suggests that a Poisson distribution generated the data, Poisson regression should be used to analyze the data.

Introduction

Utilizing an analysis of variance (ANOVA) or general linear model (GLM) on insect count data is oftentimes problematic. In many cases, due to the large number of zero counts, data transformations, in an attempt to approach normality, are usually applied using rule of thumb or tradition without any particular justification (Krebs 1989). Even with transformations, violation of the assumptions sometimes occurs and transformations are not routinely recommended (Southwood 1978). Further, the adequacy of the transformation must be checked prior to analysis. In cases where the frequency distribution is severely skewed, analysis based on a normal distribution may still result in errors (Southwood 1978). Part of the problem associated with routinely transforming data to meet normality assumptions is that the underlying distribution which generated the data is not known. Other analysis methods use indices, such as k values from the negative binomial distribution, but these can be highly suspect due to limitations in their biological interpretation (Taylor *et al.* 1979). Many insect data sets have been described using distributions such as the negative binomial, Neyman type A or Polya-Aeppli

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(Kemp 1987); however, the underlying theory of the behavior or the assumptions required to accurately apply these models are ignored (White and Bennetts 1996). If parametric methods prove unsuccessful, non-parametric methods are available. While these methods are referred to as distribution-free tests, they have limited application in a many variable situation (Zar 1984). Superior testing and estimation procedures are being developed, such as the bootstrap and permutation tests (Good 1994). Although these methods can be used in a manner that relies exclusively on the observed frequency of the data, their power can be improved if the generating distribution is known and used to assist in the resampling. Therefore, even these methods do not provide an escape from the need to carefully formulate a model of the data generating process.

Few analysis methods can adequately handle data sets with variables which are both continuous and categorical, a disproportionate number of zero counts and a low and unequal number of replicates. In situations such as these, more complex analytical methods are required. The data set in question refers to data collected while studying the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae), in British Columbia seed orchards (see Blatt and Borden 1996). This insect is considered a pest on many conifer species (Krugman and Koerber 1969; Ebel and Yates 1974; Ruth 1980; Hedlin *et al.* 1980; Schowalter *et al.* 1985; Pasek and Dix 1988; and Schowalter 1994, 1997). *L. occidentalis* overwinters as an adult, emerging in spring to seek out seed orchards and suitable hosts. Adults mate and females oviposit their eggs on the needles beginning in mid-May and continuing throughout the summer. Females repeatedly select host trees for oviposition during this time. Nymphs hatch and proceed through 5 instars, becoming adults in late July or early August. All life stages feed on the developing cones. In the fall, following harvest, adults leave their hosts and seek overwintering sites.

Our objectives here are three-fold: 1. to develop and utilize a theoretically suitable analysis method to describe the host selection process of an insect; 2. to test the hypothesis that tree characteristics change the probability of a tree being selected; and 3. to determine which variables are significant in the model.

Methods

Objective 1: Theoretical framework

The best analysis method is one that is consistent with a theoretical model of the behavior of the organism being studied. Three steps which should be followed to determine the optimum method of analysis are: 1. a precise theory of the behavior of the organism that underlies the data must be developed; 2. the distribution, as implied by the behavioral model, identified; and 3. a statistical analysis based on the distribution located or developed and used to analyze the data. By applying these steps to the behavior of *L. occidentalis* we will show that Poisson regression is the appropriate analysis method for the count data collected. With the assistance of powerful computers, complex analysis methods such as Poisson regression can be effectively applied. Therefore, excessive dependence on the central limit theorem need not underlie hypothesis testing.

Objective 2: Hypothesis Testing

Organization of the Data — Data sets were compiled for two Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, orchards, Mt. Newton 1 and 2, first and second generation orchards, respectively, located at Mt. Newton Seed Orchards, Timber West Ltd., Saanichton, BC, and two lodgepole pine, *Pinus contorta* L., orchards, Kal 1 and 2, reference numbers 230 and 307, respectively, located at Kalamalka Seed Orchards, B.C. Forest Service, Vernon, BC (see Blatt and Borden 1996). Mt. Newton 1 and 2 were surveyed consecutively from 1992-1994 and the following data was collected from each tree: tree height (measured in metres), cone density (ranked from 1-5 with 1 being for very few cones and 5 being for many cones), and gibberellin use (yes or no). Kal 1 and 2 were surveyed consecutively from 1993-1995 and the following data collected: tree height, cone density or actual cone numbers, yield, and half-cone seed counts. Insect surveys, conducted by sampling the entire tree, for adults and nymphs, occurred in either July or August. For all data sets analyzed, the number of trees per clone was at least 3, but varied to as high as 41 trees per clone in the lodgepole pine orchards.

Analytical methods — Limdep (Limited Dependent Variables) version 7.0 (Greene 1995), obtained from Econometric Software Inc., Belport, New York, and installed on a PC was used to analyze the data.

Graphical examination of the data disclosed a severe deviance from normality (Fig. 1). To adjust for this, *L. occidentalis* counts (adults and nymphs separately) were transformed using the square root transformation and univariate analyses in SAS (SAS 1988) conducted to determine the adequacy of the transformation. In all cases, the skewness was not corrected (adults: skewness ranged from -0.14 to 3.14 and kurtosis from -0.816 to 21.6, probability of originating from a normal distribution 0.0001; nymphs: skewness ranged from 0 to 3.37 and kurtosis from 1.65 to 22.72, probability of originating from a normal distribution 0.0001). Thus, any analysis based on the normal distribution would most likely generate questionable results, even when its theoretical appropriateness is not considered. As such, ANOVA was not deemed appropriate and the negative binomial distribution, with its exponent parameter *k*, was used to describe the distribution of *L. occidentalis* within orchards (Blatt and Borden 1996). However, as *k* has been shown to be valuable as a descriptive statistic only (Taylor *et al.* 1979), evaluation of specific variables was not possible.

Three different models were generated from each data set. The first model used clone and tree characteristics as the explanatory variables (whole model), the second model was restricted to only clone and the third model was restricted to only tree characteristics as explanatory variables. Insect counts for adults and nymphs were analyzed separately. The goodness of fit of the data to the Poisson distribution was evaluated as part of the program in Limdep with G^2 and R^2 values being generated. G^2 is the deviance measure defined as

$$2\sum_i\left[y_i\log\left(\frac{y_i}{\lambda_i}\right)\right]$$

where y_i are the observed count values and λ_i are the estimates of the Poisson means. The reported R^2, analogous to that used in standard linear regression, is based on the Pearson residuals for the Poisson model. It is based on the ratio of the standardized fitted variance and the standardized raw variance (Gurmu and Trivedi 1996). Overdispersion of the data can occur when the data exhibit extremely long tails. The assumption of the variance equaling the mean (a major assumption of the Poisson regression) may be violated. One means to discern the amount of overdispersion is to allow the variance to fluctuate with the mean. In Limdep this is achieved by running a negative binomial analysis on the data and comparing the coefficients with those obtained from Poisson regression. The net result is an α value which, to ensure that overdispersion is not a serious problem, must be close to 1. Another goodness of fit descriptor is the CAIC or Consistent Akaike Information Criteria. The CAIC = -2(log-likelihood value)+(# of free parameters)(Log(N)+1). Unlike the AIC (Akaike Information Criteria), the CAIC imposes a sample size penalty and is asymptotically consistent (Gurmu and Trivedi 1996). Comparison of the CAIC generated from a Poisson regression and a negative binomial is similar to the comparison of the log-likelihood values; smaller values indicate a better fit of the data to the distribution (White and Bennetts 1996).

To test the hypothesis that tree characteristics affect the probability of a tree being chosen by *L. occidentalis*, a log-likelihood comparison of the unrestricted model (clone and tree characteristics

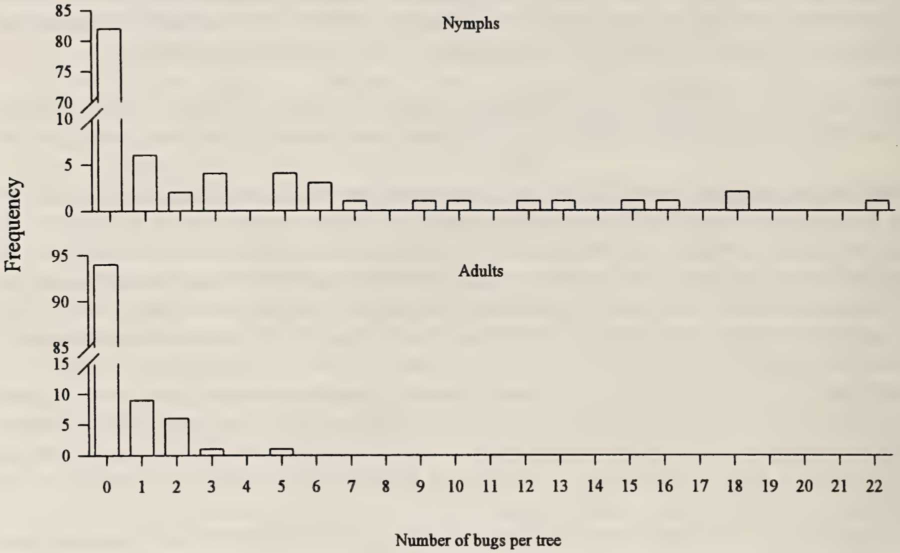

FIGURE 1. Frequency of Douglas-fir trees harboring *Leptoglossus occidentalis* nymphs and adults from Mt. Newton 2 surveyed in July, 1992.

analysis) with the restricted models (clone or tree characteristics analysis) was done. The Likelihood Ratio Test (Davidson and MacKinnon 1993) generates a G value which has a chi-square distribution and a p value which indicates whether imposing a restriction significantly changes the fit of the model. For example, restricting the analysis to only clone is in effect a look at how the tree characteristics impact on the model, because the tree characteristics, in this analysis, are forced to have zero effect. If the p value is significant, it indicates that tree characteristics are important in the model and without them, the model is significantly changed from the unrestricted (where all variables are included) model. A non-significant p value indicates that including tree characteristics in the model does not significantly increase the explanatory power of the model.

Objective 3: Evaluation of variables

To demonstrate the benefits of using a Poisson regression, we chose one orchard in one year as an example and evaluated the importance of the variables to the model. Using Mt. Newton 2 - 1992, as an example, we analyzed the data set for nymphs. This model had results which were significant for several variables and included both categorical and continuous data. For the analysis, a constant term, referred to as the base case throughout, was chosen. The base case is used as a basis of comparison. Ideally, the worst case scenario is chosen as then any significant variables are a result of the response being greater than the base case. In the *L. occidentalis* surveys, there were many trees harboring no insects at all. However, selecting one of these is problematic. Results generated by a Poisson regression are relative to the base case and not absolute like they are in ANOVA. Therefore, relative to zero, any tree with more than zero bugs has infinitely more insects. This yields large coefficient values which are difficult to interpret. To avoid this problem, we chose as a base case a clone harboring a very small number of adult and nymph *L. occidentalis*. For the clone variable, we chose different base cases for adults and nymphs. For cone density and gibberellin, the highest cone density ranking (5) and trees not injected were used as the base cases, respectively.

Interpretation of the Results — Categorical and continuous data within the model were handled differently with respect to interpreting the relative risks. Categorical data, *i.e.* cone density, had each category compared with the highest cone density value of 5. All relative risks generated refer to the amount of increase, if greater than 1, or decrease, if less than 1, compared with the highest cone density value. As an example, if a cone density of 2 generates a relative risk of 9.55, this means that trees with a cone density of 2 are 9.55 times more likely to have insects on them than trees with a cone density of 5. Conversely, if cone density of 2 generates a relative risk of 0.65, this means that trees with a cone density of 2 are less likely, by 0.65 times, to have insects on them compared to trees with a cone density of 5. Continuous data, *i.e.* tree height, does not generate relative risk in relation to only one lower valued situation. Relative risks generated for continuous variables refer to the amount of increase in insect numbers which can be expected with an increase in one unit of measure, *i.e.* a metre. So, if the relative risk of tree height equals 1.07 for a particular orchard, for every metre of tree height, it would be expected that the number of insects would increase by 1.07 times, *i.e.* ~ 7% increase. These values may be important for orchard managers or pest management specialists who are interested in knowing which trees are more likely to be infested than others.

Limdep Specifics

To determine the coefficient values, Limdep utilizes the Newton method to maximize the log of the likelihood function. For these analyses, at least fifty iterations of the model are calculated before final estimates are obtained for each parameter. The final result, in the form of coefficients, is generated for each parameter. The basic form of the Poisson model for discrete random variable, Y, observed frequencies, y_i, I=1,...,N, and regressors $x_i = [x_{1,i} \;\; x_{2,i} \;\; \dots \;\; x_{k,i}]$ for each observation,

$$prob\left(Y=y_i\right) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}, \quad y=0,\ 1,\ \dots$$

where $\ln\lambda = \beta' x_i$

and $\beta' x_i = \alpha + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_k x_{ki}$

In this model, λ_i is both the mean and variance of y_i. In less mathematical terms, $\beta = [\beta_1 \;\; \beta_{21} \dots \;\; \beta_k]$ represents the coefficient generated for each variable added to the model. Using these coefficients, a λ value can be calculated for each tree, based on individual tree characteristics, which represents the estimated mean number of insects expected. The analysis also generates a Z score which indicates whether the variable is important in the model. Relative risks for each variable were generated using the equation:

$$Relative\ Risk = \frac{\exp\left(\beta_1\right)}{\exp\left(\beta_C\right)}$$

(Maldonado and Greenland 1993) where β_1 is the coefficient for the variable and β_c is the coefficient of the base case. However, setting exp(β_1) to 1 results in the equation being merely divided by one and calculation of the relative risk becomes: Relative Risk = exp(β_1). All relative risk values generated are compared to this base case. When working with a Poisson distribution, the impact of a variable is multiplicative, rather than additive, as is the case for an ANOVA. The relative risk is the multiplicative analogue to a difference between means, where the base case is the control.

Results and Discussion

Objective 1: Theoretical framework

To address the first of the three steps required to develop the theory, host selection behavior of *L. occidentalis* in a seed orchard must be examined. In the spring, *L. occidentalis* adults leave overwintering sites and fly to an orchard where acceptable hosts are located. *Leptoglossus occidentalis* is a strong flier (Schowalter 1984) and can possibly survey a large section of an orchard prior to selecting a host. Therefore, any insect entering an orchard has a large number of trees to choose from. Theoretically, if all trees within a seed orchard were genotypically and phenotypically the same or if host selection did not depend on tree characteristics, each tree would be equally acceptable, so that the probability of any individual tree being chosen would be the same and no host preference would be observed. We hypothesize that the probability of a particular tree being chosen for feeding and oviposition is based on tree characteristics, such as height (possibly indicating better host quality) and cone density (indicating food availability). Once an acceptable host is selected, mating and oviposition occur. The number of eggs oviposited is taken as an indicator of how preferred the tree is. We assume that each *L. occidentalis* adult behaves in the same way and that each year adults enter the orchard from all directions, meeting the requirements of independence and randomness, respectively. These assumptions allow us to consider the observed number of bugs on each tree to be draws from an identical distribution.

For the second step, we use the postulated behavioral model to identify the distribution that lies behind the data collected. With respect to *L. occidentalis*, the probability that an insect chooses a particular tree, from an orchard of identical trees, is 1/n, where n is the number of trees within the orchard. Given that n is large, the probability of an individual tree being chosen is small. The number of insects choosing a particular tree within an orchard of identical trees therefore follows a Poisson distribution. If *L. occidentalis* exhibits a host preference, one would expect to see larger probabilities associated with preferred trees. For the orchards studied, a few insects had many trees to choose from. As a result, there were many trees which harbored no insects at all and only a few trees which had insects on them. As in many similar studies, when the number of positive responses is small in comparison to the total number of individuals being studied, the Poisson model should provide a reasonable approximation to the exact distribution of the data (Frome *et al.* 1973; Breslow and Day 1987; Lawless 1987).

For the third step, a review of the literature is required. Other situations where individuals experience repeated events, and Poisson regression has been used to analyze the data, can be found in cancer research (Boffetta *et al.* 1992; Koivusalo *et al.* 1994; Morrison *et al.* 1994; Plu-Bureau *et al.* 1994), epidemiology (Frome and Checkoway 1985), mortality studies (Mackenbach *et al.* 1992; Tolbert *et al.* 1992; Schouten *et al.* 1993; Segal and Neuhaus 1993), environmental impact studies (Alexander *et al.* 1992; Ray *et al.* 1992; Schwartz 1994), medicine (Gail *et al.* 1980; Bartoszynski *et al.* 1981; Farewell and Sprott 1988; Blackwelder 1993; Lavange *et al.* 1994), equipment reliability studies (Crow 1974; Ascher and Feingold 1984), economics (Hausman *et al.* 1984) and sociology (Heckman and Singer 1985). In all cases, the behavior of the organism or entity being studied has followed a Poisson distribution. As a result, use of Poisson regression to analyze the data, which is based on the Poisson distribution, is appropriate.

There are four important reasons to use the Poisson distribution in cases such as these (Dean 1988): 1) it can be derived theoretically as the distribution of counts using simple assumptions; if events occur randomly and independently with the average rate of occurrence being constant, then the number of events that occur in a fixed time interval has a Poisson distribution; 2) it is the limiting form of certain distributions including the binomial and the superposition of many arbitrary counting processes; 3) it is a member of the exponential family so that a unique, unbiased, minimum variance estimator of the mean of the distribution exists, this estimator being a function of the sufficient statistic and 4) it frequently provides an adequate approximation to the distribution of random counts. A fifth reason for using the Poisson distribution is that it enables more meaningful biological interpretation of a model and its parameters than merely formal goodness-of-fit testing (Douglas 1994).

To demonstrate that Poisson regression is appropriate with a less complex example, suppose we have an orchard with only two types of trees, one preferred by *L. occidentalis* and the other which is not. We want to demonstrate statistically that *L. occidentalis* has a preference for one type of tree. Typically, observations of the number of insects on trees of each type would be collected. With this data a mean number of insects per tree for each type of tree would be calculated, and then a test for differences between the means using an ANOVA (or in this simple example, a student's t test). Although a standard practice, there is a serious problem with this methodology. When using an ANOVA this way, it is implicitly assumed that there is a true mean number of insects for each tree type. Since the number of insects that inhabit the orchard is itself random, the mean number of insects per tree is also random. One way to treat this problem is to compare proportions instead of numbers of insects. The percentage of insects in the orchard which chose trees of one type would be compared to the percentage that chose the other type. This is certainly better than using an ANOVA directly, but there is a better way.

Let's think of each *L. occidentalis* having to decide which tree to alight upon. Is it reasonable to believe that there is a small chance that any particular *L. occidentalis* will choose the less preferred tree type? If we allow *L. occidentalis* to choose the less preferred tree type, it means that for any particular insect, there is a certain probability that it will choose one of the preferred trees, and a smaller, but not zero, probability that a less preferred tree will be chosen. Assuming that *L. occidentalis* chooses trees of a single type with equal probability — the trees are not different in any way, so there is no reason to expect the probabilities to be different — then each tree of each type will have the same chance of being chosen. However, a tree of the preferred type is more likely to be chosen than a tree of the less preferred type. If we compare two trees of different types, then we will see that the more preferred tree is relatively more likely to be chosen; there is a higher *relative risk* that an insect will be found on a preferred tree. Regardless of how many insects live in this particular orchard, if we believe that all the insects choose hosts in the same way, then the relative risk will be a constant, a number which we can then try to identify.

In this example, the percentage of the insects that chose the preferred tree type is a good estimate of the true probability. However, to compare the probabilities we are faced with a set of messy transformations and assumptions about normality. We can improve on this by using our proposed insect behavior to get at the true distribution of insect counts. Each *L. occidentalis* that is going to land on a tree in the orchard has to choose a tree. Let us assume that *L. occidentalis* does not rule out any trees, which means that there is a non-zero probability that any tree in the orchard will be chosen. Now let's look at one tree. Before we collect our observations, we do not know how many insects live in the orchard. We do know that there is positive probability that each tree will have some insects on it. We also believe that each insect behaves the same. If we are looking at the tree, then technically each insect that inhabits the orchard is a trial, and the number of insects which are found on this tree are successes. The probability that this tree will be chosen is constant, since each insect behaves the same, and independent of the number of trials, or total number of insects, and the total number of insects is itself random. The counts on any individual tree are therefore repeated draws on an independent, identical distribution with a small probability of success for any given trial. This is a Poisson distribution.

Objective 2: Hypothesis Testing

Goodness of fit statistics obtained from the Poisson regression analysis indicate that the data fit a Poisson distribution (Tables I and II). The R^2 values were the greatest for the whole model and in many cases were >0.60 suggesting a really good fit of the data to the distribution. This supports our theoretical model. While in some cases, overdispersion was possibly a problem ($\alpha > 2$), examination of results generated using the negative binomial distribution showed no significant differences with respect to the coefficients. Further, even if overdispersion is present, this does not in and of itself imply that the negative binomial distribution is adequate or that this alternative is the correct one (Gurmu and Trivedi 1996). The larger α values associated with the restricted models (clone or tree characteristics alone) as compared to the unrestricted model (all variables) suggest that the restricted models are incomplete. It may be useful to consider these values as an indicator that more variables are required to examine the relationship between insect counts and the tree characteristics. Further, the Log-likelihood and CAIC values decreased only slightly with the negative binomial distribution suggesting that the fit is not that much improved over the Poisson distribution.

Likelihood Ratio Test values comparing the unrestricted model to two restricted models show that adding clone and tree characteristics significantly changes the model (Tables III and IV, adults and nymphs, respectively). For adults, the effect of adding clone to the model can be seen in the *p* values of restricted model 2 (analysis using only tree characteristics). In eight of 11 instances, clone was found to be highly significant for explaining the distribution of *L. occidentalis* within a seed orchard. For nymphs, the effect was even more dramatic and in 10 of 11 instances clone was a highly significant factor. Even more interesting is the effect of tree characteristics (restricted model 1). The effect of adding tree characteristics to the model was significant in eight of 11 instances for adults and in all instances for nymphs. These results suggest that for most orchards, both clone and tree characteristics are important in the host selection process of *L. occidentalis*. In years where addition of tree characteristics was not significant (non-significant *p* value in restricted model 1), addition of clone was significant, and conversely, if addition of clone was not significant, addition of tree characteristics was. There was only one instance where both restricted models were not significant (Kal 2 - 1994, adults).

Objective 3: Evaluation of variables

In many analyses, evaluating differences between variables is a primary objective. In an ANOVA, means are calculated and variances used to determine how close two, or more, populations are to each other. Poisson regression evaluates these differences by calculating probabilities. Table V provides a list of all the variables used in the Poisson regression model for nymphs surveyed at Mt. Newton 2 - 1992. Means (± SE) for each variable were provided to aid the reader in understanding the data; they are not used in the Poisson regression. Relative risks are presented for comparison with the base case. Each relative risk is generated as if no other variable were present in the model. For example, in Table V, clone 3146 was chosen as the base case for the clone variable. All other clones have a 'risk' of being chosen by *L. occidentalis* which is 'relative' to this base case. As clone 3146 had few bugs, those clones with insects should have high relative risk values and those with no insects should have low relative risk values. Relative risk values for clones with bugs ranged from 1.06 to 27.87. All clones with no insects had relative risk values <0.000001. When looking at the means for each clone, some clones have higher insect numbers but are not significant (clone 3117), while other clones with fewer insects are (clones 3175 and 3080). Although both clones 3117 and 3080 have the same number of trees, the standard error of clone 3080 is smaller than that of clone 3117, indicating that the insects were more spread out among the trees, *ie*. the insects were not just on one tree. Similar examinations follow for each variable included in the model. Cone density rankings of 1, 2, 3 and 4 are compared with cone density ranking 5 (base case). Trees injected with gibberellins are compared

TABLE I. Goodness of fit and amount of overdispersion statistics of the data used in Poisson regression. Comparison of the models with results from analysis using the negative binomial distribution showing overdispersion (α) to be minimal, and the fit of the data to be not significantly better. Each value was generated from a model evaluating the relationship between adult *L. occidentalis* and various tree characteristics, separately (clone only or tree characteristics) or in combination (all variables).

			Poisson regression				Comparison with Negative Binomial		
Orchard	Year	Model	Log-likelihood values	G^{2+}	R^{2+}	CAIC^{++}	Log-likelihood values	α^{+++}	CAIC
Mt. Newton 1	1992	All variables *	-62	68	0.61	268	-60	0.45	264
		Clone only	-65	75	0.57	256	-89	0.49	251
		Tree characteristics **	-102	148	0.15	227	-63	3.25	201
	1994	All variables	-370	527	0.54	875	-233	1.51	601
		Clone only	-483	754	0.34	1086	-257	2.36	633
		Tree characteristics	-508	804	0.29	1036	-250	2.14	520
Mt. Newton 2	1992	All variables	-40	40	0.65	178	-40	0.08	177
		Clone only	-51	62	0.46	182	-49	0.89	178
		Tree characteristics	-67	93	0.19	155	-61	2.48	143
	1993	All variables	-7	1	0.98	165	-7	0.03	165
		Clone only	-16	19	0.76	171	-15	0.94	169
		Tree characteristics	-27	40	0.50	72	-22	4.63	63
	1994	All variables	-289	472	0.44	688	-132	2.82	375
		Clone only	-315	525	0.38	729	-137	3.34	372
		Tree characteristics	-414	723	0.15	844	-154	5.87	323
Kal 1	1993	All variables	-69	75	0.57	358	-69	0.11	357
		Clone only	-76	89	0.49	359	-75	0.33	357
		Tree characteristics	-102	142	0.18	223	-98	1.78	213
	1994	All variables	-263	295	0.48	727	-239	0.65	677
		Clone only	-265	299	0.47	724	-239	0.66	671
		Tree characteristics	-395	559	0.02	800	-293	2.24	597
	1995	All variables	-387	528	0.30	1173	-376	1.28	1151
		Clone only	-399	552	0.27	1188	-385	1.52	1161
		Tree characteristics	-490	734	0.03	993	-456	4.12	925

TABLE I - continued

Orchard	Year	Model	Poisson regression: Log-likelihood values	Poisson regression: G^{2+}	Poisson regression: R^{2+}	Poisson regression: CAIC^{++}	Comparison with Negative Binomial: Log-likelihood values	Comparison with Negative Binomial: α^{+++}	Comparison with Negative Binomial: CAIC
Kal 2	1993	All variables	-48	55	0.49	216	-46	0.62	214
		Clone only	-49	57	0.47	200	-48	0.53	198
		Tree characteristics	-73	106	0.03	168	-67	3.42	155
	1994	All variables	-101	92	0.25	305	-103	0.20	308
		Clone only	-104	96	0.21	300	-104	0.06	301
		Tree characteristics	-114	117	0.04	241	-115	0.20	242
	1995	All variables	-2665	4341	0.11	5491	-1469	5.57	3100
		Clone only	-2679	4369	0.10	5515	-1474	5.67	3106
		Tree characteristics	-2914	4838	0.007	5836	-1510	6.69	3030

[+] Goodness of fit statistics: G^2 - deviance measure, and R^2 - based on the Pearson residuals for the Poisson model (see Gurmu and Trivedi 1996).

[++] CAIC - consistent Akaike Information Criteria (see Gurmu and Trivedi 1996).

[+++] α - indicator of overdispersion. The larger the number, the greater the overdispersion.

[*] All variables - for Mt. Newton 1 and 2: clone, tree height, cone density and gibberellin application. For Kal 1 and 2: clone, tree height, cone density, yield, and half-cone seed counts.

[**] Tree characteristics - all characteristics listed above except clone.

TABLE II. Goodness of fit and amount of overdispersion of the data to the Poisson distribution. Comparison of the models with results from analysis using the negative binomial distribution showing overdispersion (α) to be minimal, and the fit of the data to be not significantly better. Each value was generated from a model evaluating the relationship between nymphal *L. occidentalis* and various tree characteristics, separately (clone only or tree characteristics) or in combination (all variables).

			Poisson regression				Comparison with Negative Binomial		
Orchard	Year	Model	Log-likelihood values	G^{2+}	R^{2+}	$CAIC^{++}$	Log-likelihood values	α^{+++}	CAIC
Mt. Newton 1	1992	All variables *	-118	1690	0.62	380	-83	2.23	311
		Clone only	-154	241	0.46	433	-93	3.85	310
		Tree characteristics **	-178	289	0.35	379	-108	7.17	239
	1994	All variables	-161	234	0.53	458	-109	2.09	353
		Clone only	-200	311	0.37	519	-119	3.39	358
		Tree characteristics	-236	384	0.22	493	-133	5.39	285
Mt. Newton 2	1992	All variables	-211	324	0.52	520	-122	3.01	342
		Clone only	-237	376	0.44	554	-129	3.86	337
		Tree characteristics	-357	616	0.09	736	-145	7.99	312
	1993	All variables	-34	39	0.81	218	-34	0.06	218
		Clone only	-49	71	0.66	238	-35	2.67	209
		Tree characteristics	-86	144	0.31	191	-50	17.06	119
	1994	All variables	-300	505	0.53	709	-120	3.23	350
		Clone only	-333	573	0.46	765	-124	3.62	346
		Tree characteristics	-495	896	0.16	1005	-142	7.65	300
Kal 1	1993	All variables	-126	188	0.62	473	-84	2.97	388
		Clone only	-138	211	0.57	483	-90	3.97	388
		Tree characteristics	-234	403	0.18	485	-116	15.1	250
	1994	All variables	-143	177	0.38	485	-136	1.02	472
		Clone only	-146	184	0.35	486	-137	1.15	467
		Tree characteristics	-193	278	0.02	396	-165	3.07	341
	1995	All variables	-1390	2250	0.30	3179	-840	6.53	2078
		Clone only	-1489	2447	0.24	3368	-854	7.28	2098
		Tree characteristics	-1794	3058	0.05	3601	-920	11.46	1852

TABLE II - continued

			Poisson regression				Comparison with Negative Binomial		
Orchard	Year	Model	Log-likelihood values	G^{2+}	R^{2+}	$CAIC^{++}$	Log-likelihood values	α^{+++}	CAIC
Kal2	1993	All variables	-5	0	1.00	130	-5	0.20	131
		Clone only	-15	20	0.68	132	-13	1.78	128
		Tree characteristics	-28	45	0.31	77	-20	13.75	62
	1994	All variables	-70	77	0.53	241	-67	0.43	236
		Clone only	-75	87	0.46	242	-71	0.64	235
		Tree characteristics	-107	151	0.07	227	-92	2.63	196
	1995	All variables	-451	641	0.18	1064	-436	2.03	1033
		Clone only	-453	645	0.18	1063	-438	2.06	1032
		Tree characteristics	-2914	773	0.01	5836	-486	4.28	981

+ Goodness of fit statistics: G^2 - deviance measure, and R^2 - based on the Pearson residuals for the Poisson model (see Gurmu and Trivedi 1996).

++ CAIC - consistent Akaike Information Criteria (see Gurmu and Trivedi 1996).

+++ α - indicator of overdispersion. The larger the number, the greater the overdispersion.

* All variables - for Mt. Newton 1 and 2: clone, tree height, cone density and gibberellin application. For Kal 1 and 2: clone, tree height, cone density, yield, and half-cone seed counts.

** Tree characteristics - all characteristics listed above except clone.

TABLE III. Likelihood Ratio Test statistics for adult *L. occidentalis* in four orchards over four years of surveys. G values compare an unrestricted model with two restricted models: 1 (clone only) and 2 (tree characteristics). *P* values for restricted model 1 indicate the significance of including tree characteristics in the unrestricted model. *P* values for restricted model 2 indicate the significance of including clone in the unrestricted model.

Orchard	Year	Unrestricted model[a]		Restricted model 1[b]				Restricted model 2[c]			
		VLLF[d]	df	VLLF	df	G value[e]	*P* value	VLLF	df	G value	*P* value
Mt. Newton 1	1992	-62.31	43	-65.75	37	14.96	0.021	-102.43	6	80.24	<0.0001
	1994	-370.24	41	-483.73	36	162.52	<0.0001	-508.61	5	276.74	<0.0001
Mt. Newton 2	1992	-40.29	31	-51.50	25	29.81	<0.0001	-67.02	6	53.46	0.001
	1993	-7.62	49	-16.75	45	18.26	0.001	-27.01	5	38.78	0.695
	1994	-289.12	36	-315.94	31	86.06	<0.0001	-414.82	5	251.40	<0.0001
Kal 1	1993	-69.73	64	-78.59	60	17.72	0.001	-102.88	4	66.30	0.269
	1994	-274.33	59	-275.41	57	2.17	0.339	-395.20	2	241.74	<0.0001
	1995	-387.51	96	-399.16	94	23.29	<0.0001	-490.21	2	205.40	<0.0001
Kal 2	1993	-48.03	38	-49.19	32	2.31	0.889	-73.58	6	51.09	0.017
	1994	-101.99	32	-104.35	29	4.72	0.194	-114.50	3	25.02	0.677
	1995	-2665.40	38	-2679.47	37	28.13	<0.0001	-2914.15	1	497.50	<0.0001

[a] Unrestricted model - evaluates the relationship between insect numbers and several variables. For Mt. Newton 1 and 2 these variables include: clone, tree height, cone density and gibberellin use. For Kal 1 and 2 includes: clone, tree height, cone density, yield, and half-cone seed counts.

[b] Restricted model 1 - evaluates the relationship between insect counts and clone.

[c] Restricted model 2 - evaluates the relationship between insect counts and tree characteristics, listed above, excluding clone.

[d] VLLF - Value of the log-likelihood function

[e] G value - generated from the Likelihood Ratio Test (Davidson and MacKinnon 1993)

TABLE IV. Likelihood Ratio Test statistics for nymphal *L. occidentalis* in four orchards over four years of surveys. G values compare an unrestricted model with two restricted models: 1 (clone only) and 2 (tree characteristics). *P* values for restricted model 1 indicate the significance of including tree characteristics in the unrestricted model. *P* values for restricted model 2 indicate the significance of including clone in the unrestricted model.

Orchard	Year	Unrestricted model[a]		Restricted model 1[b]				Restricted model 2[c]			
		VLLF[d]	df	VLLF	df	G value[e]	*P* value	VLLF	df	G value	*P* value
Mt. Newton 1	1992	-118.37	43	-154.53	37	87.04	<0.0001	-178.45	6	120.16	<0.0001
	1994	-161.63	41	-200.19	36	144.86	<0.0001	-236.95	5	150.64	<0.0001
Mt. Newton 2	1992	-211.36	31	-237.69	25	200.79	<0.0001	-357.41	6	292.10	<0.0001
	1993	-34.08	49	-49.99	45	31.82	<0.0001	-86.54	5	104.93	<0.0001
	1994	-300.00	36	-333.81	31	67.91	<0.0001	-495.11	5	390.22	<0.0001
Kal 1	1993	-121.61	64	-133.81	60	24.40	<0.0001	-234.39	4	225.56	<0.0001
	1994	-147.41	59	-152.28	57	9.74	0.008	-193.34	2	91.85	0.002
	1995	-1390.51	96	-1489.10	94	197.19	<0.0001	-1794.47	2	807.93	<0.0001
Kal 2	1993	-5.05	38	-15.34	32	20.59	0.002	-27.75	6	45.41	0.059
	1994	-70.19	32	-75.40	29	10.43	0.015	-107.60	3	74.82	<0.0001
	1995	-451.69	38	-453.65	37	3.93	0.047	-517.81	1	132.24	<0.0001

[a] Unrestricted model - evaluates the relationship between insect numbers and several variables. For Mt. Newton 1 and 2 these variables include: clone, tree height, cone density and gibberellin use. For Kal 1 and 2 includes: clone, tree height, cone density, yield, and half-cone seed counts.

[b] Restricted model 1 - evaluates the relationship between insect counts and clone.

[c] Restricted model 2 - evaluates the relationship between insect counts and tree characteristics, listed above, excluding clone.

[d] VLLF - Value of the log-likelihood function

[e] G value - generated from the Likelihood Ratio Test (Davidson and MacKinnon 1993)

TABLE V. Mean number nymphs/tree for each significant and non-significant variable included in the Poisson regression model for Mt. Newton 2 surveyed July, 1992.

	Variable	Mean number nymphs/tree (±SE)	n	Relative risk	*P* value
Base case	clone 3146	0.33 ± 0.33	3	1.00	n/a
	cone density 5	6.47 ± 1.96	15	1.00	n/a
	gibberellins not used	1.89 ± 0.44	99	1.00	n/a
Variables included in the model	height	n/a	n/a	1.00	0.6771
	cone density 1	0.28 ± 0.24	21	1.00	<0.000
	cone density 2	1.81 ± 0.93	21	1.00	0.1089
	cone density 3	2.81 ± 1.17	16	0.99	0.0228
	cone density 4	1.55 ± 0.76	9	0.15	0.0439
	gibberellins used	1.08 ± 1.08	12	0.68	0.0197
	clone 3177	9.00 ± 6.66	3	1.66	0.0011
	clone 3106	8.60 ± 3.66	5	0.54	0.0031
	clone 3117	4.50 ± 4.50	4	0.49	0.0530
	clone 3100	4.25 ± 3.92	4	27.87	0.0166
	clone 3080	3.50 ± 2.18	4	20.12	0.0266
	clone 3175	3.44 ± 1.70	9	7.53	0.0369
	clone 3153	2.50 ± 2.50	4	11.87	0.1593
	clone 3130	1.80 ± 1.20	5	10.16	0.1958
	clone 3132	1.50 ± 1.50	4	8.46	0.3179
	clone 3084	1.00 ± 0.63	6	4.42	0.6003
	clone 3114	1.00 ± 1.00	3	3.95	0.6478
	clone 3079	0.75 ± 0.62	8	2.96	0.5961
	clone 3111	0.71 ± 0.71	7	1.77	0.4972
	clone 3184	0.50 ± 0.29	4	1.69	0.4932
	clone 3097	0.40 ± 0.40	5	1.78	0.9624
	clone 3081	0.00 ± 0.00	5	2.11	0.9766
	clone 3096	0.00 ± 0.00	3	2.32	0.9855
	clone 3104	0.00 ± 0.00	3	1.06	0.9803
	clone 3126	0.00 ± 0.00	4	<0.000001	0.9791
	clone 3131	0.00 ± 0.00	3	<0.000001	0.9813
	clone 3133	0.00 ± 0.00	3	<0.000001	0.9831
	clone 3139	0.00 ± 0.00	3	<0.000001	0.9781
	clone 3150	0.00 ± 0.00	3	<0.000001	0.9821
	clone 3154	0.00 ± 0.00	3	<0.000001	0.9835
	clone 3225	0.00 ± 0.00	3	<0.000001	0.9824

to trees not injected (base case). Tree height is the only continuous variable in this model. A mean number of nymphs/tree height could not be calculated. As such, the important value here is the relative risk.

In this example, five clones, three cone densities, and trees injected with gibberellin were found to be significant (Table V). Tree height was not significant. Biologically, these results can be interpreted as indicating that female *L. occidentalis* prefer to oviposit their eggs on specific clones with cone densities of 3 or 4 and trees injected with gibberellins. Tree height was not an important indicator of a suitable host. In a preliminary analysis of the data, the negative binomial distribution and its exponent parameter *k* was used to describe the distribution of *L. occidentalis* in orchards (Blatt and Borden 1996). However, due to *k* being valuable as a descriptive statistic only (Taylor *et al.* 1979) and evaluation of specific variables not being possible, other methods were sought. An ANOVA model including all variables was attempted but problematic due to assumption violations (see *Analytical methods*) and separate analyses (linear regression evaluating the relationship between insect counts and tree height; Spearman's rank correlation analysis for the effect of cone density; chi-square analysis to evaluate the effect of flowering time and gibberellin injection) did not disclose any significant relationships (Blatt and Borden 1996).

Conclusion

Unlike an ANOVA, which was unable to integrate many variables together into a single model without distorting the data itself or violating the assumptions, Poisson regression was able to evaluate and generate estimations of the importance of each variable within a single model. This method will be useful for many other insect species which utilize a host selection behavior which is theoretically based on a Poisson distribution. Being able to incorporate different kinds of variables into a single model which theoretically fits the biology of the insect gives greater credibility to the analysis done and to the conclusions generated. Three steps required to justify use of a distribution to analyze a data set have been outlined and evaluated with respect to the data. Use of the Poisson distribution fits to the data generating process while the normal distribution is only a large sample approximation; therefore, the appropriate distribution upon which the analysis should be based is the Poisson. When analysis packages are available which can handle these more complex models and analyses, there is little reason to rely on the central limit theorem when test methods consistent with theoretical distributions are available.

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HEXANAL AS AN ATTRACTANT FOR THE CARROT RUST FLY *PSILA ROSAE* (DIPTERA: PSILIDAE) FOR MONITORING ADULTS IN ONTARIO

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Abstract

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The aldehyde, hexanal, presented in vented 1.5 ml microcentifuge vials attached to Bristol board or Acrylite® sticky traps, significantly increased captures of second-generation carrot rust fly, *Psila rosae* (Fab.), adults in carrot plantings at Holland Marsh, Ontario, in three experiments in 1984-1990. Captures of second-generation adults were also increased significantly when hexanal was incorporated into the trap adhesive (Tangletrap®) at a concentration of 1:10 w:w. Significant increases in captures of first-generation adults were observed in only one of six experiments.

Introduction

The carrot rust fly, *Psila rosae* (Fab.), is an important pest of carrots and other Umbelliferae in temperate zones, and insecticides are used extensively to protect these crops from this pest. Its biology and control were reviewed thoroughly by Dufault and Coaker (1987), and a bibliography of publications before 1985 was compiled by Hardman *et al.* (1985). Because the occurrence of and the intensity of attack by the carrot rust fly varies greatly with location and seasonal conditions, monitoring adult populations using various types of traps has been an important tool in the management of this pest. Monitoring programmes have been developed or tested in Ontario (Stevenson 1981) and British Columbia (Judd *et al.* 1985) in Canada, Washington, USA(Getzin and Archer 1983), Great Britain (Collier *et al.* 1990), The Netherlands (Den Ouden and Theunissen 1988), Switzerland (Freuler and Fischer 1982), Denmark (Esbjerg *et al.* 1983), and Poland (Legutowska 1984). These programmes have made possible significant reductions in the amount of insecticides used to control the carrot rust fly.

Because these workers used different types of traps, different methods of deployment, and worked in differing conditions and surroundings, it is difficult to compare the threshold trap catches that have been suggested or recommended for use in pest management programmes.

There has been no definitive demonstration of a consistent relationship between trap captures of adults and the amount of crop damage. However, all thresholds that have been reported represent a relatively low level of adult activity. Stevenson (1981) recommended sprays in experimental plots if adult numbers reached 0.2 flies per trap per day (FTD), and that is also the threshold used in the pest management programme operated in the Holland Marsh in Ontario by the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) (Chaput 1993). Getzin and Archer (1983) applied soil insecticides if one adult per trap was captured in a 7-day exposure. Legutowska (1984) used a threshold of 2 adults per water trap on three consecutive days. Esbjerg *et al.*(1988) used thresholds of 0.3 to 1 FTD, depending upon various factors of location and conditions. Percy-Smith and Philipsen (1992) recommended treatment with insecticide at 0.3 FTD.

Geurin and Visser (1980) identified a number of carrot leaf volatiles that elicited electroantennogram responses by the carrot rust fly, and Geurin *et al.* (1983) reported that certain of these compounds attracted carrot rust fly adults to sticky traps in the field. One of these compounds, the aldehyde hexanal, is readily available and relatively inexpensive, suggesting that it might be a useful aid in the monitoring of the pest. This paper presents the results of a study of the use of hexanal in the monitoring of carrot rust fly adult activity in the Holland Marsh, Ontario's major area of vegetable culture on organic soil.

In Ontario, there are two generations of adults of the carrot rust fly annually. The insect overwinters in the pupal stage, so technically the first generation of adults, which begins emerging in late May, consists of the adults of the second generation of the previous year. The second flight, beginning in late July or early August, consists of the adults of the first generation, the progeny of which are responsible for the most serious crop injury. However, to conform to the usage of most authors, we refer here to the two flights of adults as first and second generations respectively. Because most of the carrots grown in the Holland Marsh are seeded late enough to avoid serious injury by the first generation of the carrot rust fly, it is the second generation that poses the most serious threat to carrot crops, that occasions the most extensive use of insecticides, and which presents the greatest need for an effective monitoring method.

Materials and Methods

General Methods. The trap used initially in this study was the Bristol board trap described by Stevenson (1977). After 1986, in this study and other monitoring of the carrot rust fly, we used a trap made from yellow acrylic plastic (Acrylite FF® colour no. 406-1, Industrial Plastics Canada, Fort Erie, ON), 20.4 x 15.4 cm, with adhesive applied to an area 13 x 9.5 cm at the centre of each side of the trap. The adhesive was the brush-on formulation of Tangle Trap® (The Tanglefoot Company, Grand Rapids, MI). In the field, traps were fastened, using a No. 1910 Bulldog® clip, to wooden stakes thrust into the soil of the carrot row so the mid-point of the trap was at the top of the carrot foliage. If necessary, a small amount of foliage on either side of the trap was trimmed to make room for the trap.

Hexanal (Caproaldehyde; Sigma Chemical Company, Oakville, ON)) was placed in 1.5 -ml microcentifuge vials in which a hole, 1 mm diam., was made by pushing a dissecting needle through the wall of the vial *ca.* 6 mm below the lid until the needle reached the opposite wall of the vial.

Trials were carried out at the OMAFRA Muck Research Station (MRS), Kettleby, ON, and at the Horvath farm near Bradford, ON. At MRS, plots, 25 x 13.2 m, consisted of 32 rows of carrots seeded with a hand seeder, or 24 triple rows seeded with a precision seeder. Traps were placed in 4 lines (= replicates) across the plot, *ca.* 6 to 7 m apart, with the traps 5 or 6 carrot rows apart. At the Horvath farm, traps were deployed in a portion of a commercial planting from which the grower withheld insecticides. Five traps of each type were placed *ca.* 15 m apart in alternating positions in a line across the planting *ca.* 5 m into the crop. Traps were examined at intervals of 3 or 4 days, when flies were counted and removed or the traps were replaced if necessary and hexanal vials were replenished or replaced.

When more than two treatments were compared, variance was analyzed using ANOVA (SAS Institute 1985), and means were separated using Duncan's Multiple Range Test. When only two treatments were compared, a t-test (TPAIR, SAS Institute 1985) comparing the total numbers of adults captured on each type of trap for each examination date was used. For each experiment in which a significant difference was shown between captures on baited vs non-baited traps, the linear relationship between captures on the two types of traps was determined using PROC GLM (SAS Institute 1985).

Effect of hexanal on trap captures of first-generation adults. From 1986 through 1990, six experiments were carried out comparing hexanal-baited and non-baited traps for monitoring adults of

TABLE I. Comparison of trap captures of first-generation carrot rust fly adults on traps baited with hexanal *vs*. non-baited traps. Bradford, Ontario, 1986-1990.

Date	Crop	No. days exposed	No. of counts	Mean and range of flies/trap/day		t	P
				Non-baited	Hexanal		
1986	celery	23	7	0.94 (0.1-2.1)	2.24 (1.1-3.3)	8.5	0.0001
1986	carrot	23	7	1.2 (0.5-3.1)	1.7 (0.6-2.8)	1.7	0.14
1987	celery	30	9	0.3 (0-0.75)	0.2 (0-0.5)	0.3	0.8
1987	carrot	45	12	1.3 (0.06-5.9)	2.7 (0.2-11.5)	2.4	0.3
1990	celery	24	7	0.4 (0-1.5)	0.9 (0.06-3.5)	1.34	0.13
1990	carrot	28	8	0.65 (0-1.6)	0.9 (0.3-1.25)	1.65	0.1

the first generation of carrot rust fly in carrots or celery. The pertinent details of individual experiments, with results, are listed in Table I.

Effect of hexanal on trap captures of second-generation adults. In 1984, hexanal-baited and non-baited Bristol board traps were compared for monitoring second-generation carrot rust fly adults in carrots at the Horvath farm from 9 August to 19 September. Adults were counted and removed or traps were replaced at intervals of 1 to 5 days. The total numbers of adults on 5 traps of each type were compared for 17 dates of examination by TPAIR.

In 1985, hexanal-baited and non-baited Bristol board traps were compared at MRS and the Horvath farm. At MRS, they were randomized in 4 replicates as described earlier, along with two types of traps not relevant to this study, and were exposed from 1 August until 3 September. At the Horvath farm, the traps were in place from 1 August until 18 September.

In 1990, we compared non-baited acrylic traps with acrylic traps baited with hexanal presented in vials having 1 or 4 vents. The 4 vents were equally distributed around the perimeter of the vial and made as described for the single hole. Four replicates of the 3 trap types were established in a randomized complete block design in a plot at MRS. Traps were in place from 30 July until 18 September.

In 1993, we compared Bristol board traps having hexanal added to the trap adhesive with non-baited Bristol board traps. Five ml of hexanal were stirred into 50 g of Tangle Trap®, and the mixture was applied to the traps as described for non-baited adhesive. Bristol board traps were used rather than acrylic because they could be prepared in advance and carried to the field in Ziploc® bags to reduce the loss of attractant through vaporisation. Included in this experiment were a smaller non-baited acrylic trap (15 x 15 cm, with adhesive applied to an area 15 x 12 cm) being tested by the OMAFRA pest management unit, and the milk-carton trap (also non-baited) previously used by that unit (Chaput 1993). Traps were placed in 4 replicated lines across the plot at MRS and were exposed from 4 to 30 August. Data were analyzed by ANOVA (SAS Institute 1985).

TABLE II. Effect of baiting traps with hexanal on captures of *Psila rosae* adults on Bristol board traps. Holland Marsh, Ontario, 1984-85.

Flies per trap per day							
Horvath Farm 1984			Horvath Farm 1985			MRS 1985	
Dates exposed	Non-baited	Baited	Dates exposed	Non-baited	Baited	Non-baited	Baited
			1-6 Aug	0.8	2.5	0.4	2.7
9-10 Aug	0.1	5.8	6-9 Aug	2.8	18.8	0.8	19.1
10-13 Aug	0.2	3.3	9-12 Aug	3.2	9.1	1.2	11.8
13-15 Aug	0.2	2.6	15-15 Aug	5.0	21.9	1.6	19.7
15-17 Aug	0.4	2.5	15-19 Aug	12.0	32.6	6.9	30.3
17-20 Aug	0.7	1.3	19-22 Aug	3.6	42.7	2.8	23.9
20-23 Aug	0.1	1.1	22-28 Aug	2.0	11.9	0.9	13.2
23-27 Aug	0.6	0.1	28 Aug-3 Sept	1.5	4.6	0.8	2.6
27-30 Aug	0.4	3.4	3-11 Sept	0.6	1.0	-	-
30 Aug-5 Sept	0.5	2.3	18 Sept	0.0	0.7	-	-
5-10 Sept	0.1	0.4					
10-14 Sept	0.8	3.8					
19 Sept	0.1	0.7					

Results and Discussion

Effect of hexanal on trap catches in the first generation. In 6 experiments, captures of carrot rust fly adults on hexanal-baited traps exceeded those on non-baited traps in 5 experiments, but were significantly greater in only one of the experiments, *i.e.*, in 1986 in celery (Table I). It appears evident therefore, that hexanal did not influence trap catches in the first generation as dramatically as it did, as subsequent discussion will show, in the second generation.

Effect of hexanal on trap catches of the second generation. In 1984, hexanal-baited traps captured significantly more (t=4.73, P=0.0002) carrot rust fly adults over the 39-day period than unbaited traps (Table II), and there were significantly more (t=6.9, P=0.0001) positive catches (*i.e.* trap with at least one fly captured on a given examination date) on hexanal-baited traps (83.5%) than on non-baited traps (49.4%).

In 1985, hexanal-baited traps captured significantly more carrot rust fly adults than non-baited traps from 1 August to 3 September at MRS (t=2.93, P=0.015, df=6) and from 1 August to 18 September at the Horvath farm (t=4.65, P=0.002, df=6) (Table II).

In 1990, hexanal-baited traps vented with 1 or 4 holes per vial captured significantly more adults (F=11.3, P=0.004, df=9) than non-baited traps, while there was no significant effect of varying the method of venting (Table III).

In 1993, there were significantly more adults captured on traps baited with hexanal incorporated in the adhesive than on the three types of non-baited traps (Table IV), with no significant differences between the last three (F=11.8, P=0.001, df=15).

If hexanal-baited traps were used in a monitoring programme, adjustment of thresholds would be required. To calculate suggested thresholds for use with baited traps, we first compared the regressions equations for baited *vs.* non-baited traps. Because t-tests showed no significant differences

TABLE III. Effect of presenting hexanal in vials vented with 1 or 4 holes on captures of *Psila rosae* adults on acrylic traps. Muck Research Station, Kettleby, Ontario, 1990.

Dates exposed	Flies per day per trap		
	1-hole vial	4-hole vial	Non-baited
30 Jul-2 Aug	1.2	1.4	0.5
2-3 Aug	2.3	5.3	0.8
3-7 Aug	8.0	9.1	1.8
7-8 Aug	6.3	5.3	0.8
8-10 Aug	7.6	14.5	3.6
10-13 Aug	54.8	42.6	17.0
13-15 Aug	29.0	20.4	2.9
15-17 Aug	20.6	25.8	10.0
17-20 Aug	30.5	24.8	4.5
20-23 Aug	12.5	15.3	4.3
23-27 Aug	6.8	9.9	2.6
27-29 Aug	7.6	14.7	1.5
29-31 Aug	3.6	3.0	1.0
31 Aug-5 Sept	2.3	2.0	0.3
5-12 Sept	2.5	3.7	1.4
12-18 Sept	0.4	0.6	0.2

TABLE IV. Captures of *Psila rosae* adults on Bristol board traps with hexanal incorporated in the adhesive compared with captures on three other types of non-baited traps. Muck Research Station, Kettleby, Ontario, 1993.

Dates exposed	Flies per day per trap			
	Hexanal-baited	Large acrylic	Small acrylic	Milk carton
4-5 Aug	9.3	0.0	0.3	1.5
5-9 Aug	1.6	0.1	0.6	0.5
9-11 Aug	23.1	1.0	1.1	1.5
11-13 Aug	14.4	1.6	1.0	1.0
13-16 Aug	12.3	0.8	1.8	1.3
16-18 Aug	56.4	0.9	1.0	2.8
18-20 Aug	8.4	0.9	0.6	2.1
20-23 Aug	6.0	0.8	0.7	0.6
23-25 Aug	3.8	0.0	0.5	0.1
25-27 Aug	0.6	0.1	0.3	0.6
27-30 Aug	0.2	0.0	0.0	0.3
Mean flies per trap*	184.5a	13.8b	18.8b	26.0b

* Mean number per trap 4-30 August. Means followed by the same letter were not significantly different according to Duncan's Multiple Range Test.

between either slopes or intercepts of the regression equations generated by the 1984 and two 1985 experiments that used Bristol board traps, the data for the three experiments were combined, resulting in the regression equation, $y = 3.9 + 3.4x$ ($F=39.9$, $R^2=0.58$, $P=0.0001$), where y and x = FTD on hexanal-baited and non-baited traps respectively. From this regression equation, we calculated that the equivalent to the threshold of 0.2 FTD used for non-baited Bristol board traps equalled 4.6 FTD. Similarly, using the data for acrylic traps from 1990, pooling the data for 1-hole and 4-hole vented traps yielded the equation $y = 3.5 + 2.7x$ ($F=111$, $R^2=0.79$, $P=0.0001$). From this equation, a calculated threshold equivalent to 0.2 FTD for non-baited acrylic traps was 4 FTD.

This study showed that baiting carrot rust fly traps with hexanal consistently increased captures in the second generation. While the advantage of obtaining much larger captures when adult activity is at its peak may be debated, it is likely that baited traps would improve the decision-making process when adult levels are near threshold, providing more margin for error because of the higher threshold. The relationship between trapping data and crop damage, whether or not traps are baited, needs to be better defined.

We have no evidence to explain the apparent lesser response of first-generation adults to hexanal-baited traps. The only significant difference between baited and non-baited traps occurred in celery, suggesting that adults might behave differently among plants of different size (celery transplants being much larger than carrot seedlings at the time of trapping) or differences in the volatile compounds given off by the two crops may have influenced the responses of flies to the baited traps. Or possibly the difference may have been related to seasonal environmental conditions or physiological differences between generations of the insect. Practically, the limited response of the first generation is not a serious drawback to the value of hexanal in a monitoring programme for Ontario, because of the much greater impact of the second generation.

The effectiveness of traps with hexanal incorporated in the adhesive suggests that pre-baited traps might be a viable tool in monitoring the carrot rust fly, but more study would be required to determine the most effective concentration for such traps and the duration of attractiveness in storage and transit.

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INCIDENCE OF TOMATO PINWORM, *KEIFERIA LYCOPERSICELLA* (WALSINGHAM), (LEPIDOPTERA: GELECHIIDAE) ON GREENHOUSE TOMATOES IN SOUTHERN ONTARIO AND ITS CONTROL USING MATING DISRUPTION

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Abstract

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Tomato pinworm (TPW), *Keiferia lycopersicella* (Walsingham), since the early 1990s has become a pest in greenhouse tomato production in southwestern Ontario. A survey for the incidence of this pest was conducted in the Leamington area, Essex County, Ontario from July to September, 1994 and 1995. Results showed that 13 and 24% of 45 greenhouse tomato operations were infested with TPW in 1994 and 1995, respectively. A field experiment was conducted in a commercial greenhouse tomato operation to evaluate mating disruption as a potential management tool for suppressing population densities of TPW. At low pest densities of three to four adult moths per pheromone trap per week, mating disruption provided effective control of TPW, and prevented the occurrence of economic damage.

Introduction

The tomato pinworm (TPW), *Keiferia lycopersicella* (Walsingham), is a major pest of field tomatoes in tropical and subtropical areas of the world including California, Florida, Texas, Hawaii, Mexico and the Caribbean (Schuster 1978; Lin and Trumble 1983; Jenkins *et al.*1990). In Canada, the earliest records of the TPW date back to 1946 when larvae were observed in field tomato crops and in greenhouses in southwestern Ontario. However, TPW never became established. Since then, isolated infestations were reported in British Columbia in 1970 and 1975 and in Manitoba during 1988 to 1989, when larval TPW were found in tomatoes that were imported from California (Garland 1989; Howard *et al.* 1994). Again, TPW did not become established. The next occurrence in Canada was reported from a single greenhouse tomato grower in Essex County, Ontario, 1991. By 1994, the incidence of TPW was increasing in greenhouse tomatoes and some growers reported loss in yield. One grower experienced an estimated 32,000 kg loss in fruit production due to TPW infestation (Ferguson, pers. comm.).

The early instars of TPW mine through the leaves, whereas later instars act as leaf rollers and burrow into the fruit (Trumble 1994). Thus, the larvae cause both photosynthetic reduction and direct damage to the fruit. The cryptic nature of larval development makes it difficult to effectively control TPW using pesticides. This fact has inspired considerable interest to develop other control strategies.

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Oatman (1970) has demonstrated that, in the absence of insecticides, parasitoids can suppress larval populations of TPW. He suggested that parasitoids must be integrated with other measures to achieve economic control. For field tomatoes, the use of sex pheromones for mating disruption has been shown to provide an alternative means of suppressing populations of TPW without impairing the effectiveness of their natural enemies (Jenkins *et al.* 1990; Trumble and Alvarado-Rodriguez 1993).

In response to the needs of greenhouse tomato growers who would like to know the current and potential incidence of TPW, a survey of TPW in Essex County, Ontario was conducted in 1994 and 1995. Also, because there was no control program for TPW in greenhouses, different control strategies were evaluated (chemical, mating disruption and parasitoids) for integrated pest management of TPW in Ontario. This paper reports the results of the TPW incidence survey and the evaluation of the mating disruptant, NoMate TPW® (Ecogen Inc., Langhorne, PA 19047-1810), as a potential tool for managing population densities of TPW at low levels.

Materials and Methods

TPW incidence survey. A survey was conducted during July, August and September in 1994 and 1995. Forty-five greenhouse tomato operations (>95% of the tomato growers) in the Leamington area (*ca.* 15 km^2) were surveyed. In 1994, growers were surveyed by interviewing them at Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) workshops on greenhouse pest management and through the OMAFRA Greenhouse Newsletter. All reported incidences were followed by visits to the growers' greenhouses. In 1995, growers were interviewed personally at their operations, and plants were checked where possible. An infestation was determined by the presence of TPW damage on the plant and/or by the presence of TPW.

Field trial of mating disruption. This study was conducted in a commercial greenhouse tomato operation in Leamington, Essex County. Two separate greenhouse compartments were used in the trial with one treatment per compartment. The treatment plot was 0.4 ha and the control plot was 0.2 ha. Plants (cultivar 'Trust') were transplanted the first week of January, 1995. The mating disruptant, formulated as NoMate TPW® spirals (E-4-Tridecenyl acetate; Z-4-Tridecenyl acetate) was distributed at a rate of 500 spirals/ha on 23 March and 25 May. Spirals were placed on the main stems of the plant close to the growing point. No insecticides were applied during the experiment. The population densities of TPW were monitored weekly using pheromone traps and by plant inspection. Five and four pheromone traps baited with the TPW pheromone were placed, respectively, in the treatment and control plots on 16 March to monitor male TPW. Lures in the traps were changed every two weeks, and liners as needed. Eleven and eight sampling subplots were established in the treatment (1440 plants per subplot) and control plots (960 plants), respectively. Fifteen plants were randomly selected from each sampling subplot to inspect for TPW mines and larvae. All larvae found during inspection were removed from the test plots after counting to minimize damage to the grower's crop. Treatment effectiveness was evaluated using three indices: 1) differences in population densities as measured by number of males collected on the pheromone traps, 2) differences in population densities as measured by number of larvae on the plants, and 3) level of infestation as shown by the proportion of plants that were damaged by TPW larvae.

Counts of the mean number of moths per trap per week and larvae per plant per week were transformed to square root (x + 0.5) and data for the percentage of infested plants per week were transformed to arcsin (x) before analysis of variance (ANOVA). Means were separated using the LSD test (GLM Procedure, SAS Institute 1990).

Results

TPW incidence survey. The survey showed a dramatic increase in the distribution of TPW over the two-year period among greenhouse tomato operations in the Leamington area. During the summer of 1994, TPW occurred in only six (13%) of forty-five greenhouse tomato operations, and its distribution was limited to the northeast area of the Leamington region. In 1995, the number of TPW-infested greenhouse operations increased to 11 (24%) of the surveyed greenhouse tomato operations, of which seven greenhouse operations had new infestations. All seven greenhouses were found in the western region of the survey area. In 1995, TPW infestations were also reported in two greenhouse operations outside of Essex County; one greenhouse was located in Norfolk County and another operation in Bruce County.

Mating disruption. Application of NoMate TPW® pheromone in the treatment plot caused a significant reduction (92%) in the number of moths per trap per week when compared with the control ($P < 0.05$) (Table I). In addition, a lower mean number of TPW larvae and percentage of TPW-infested tomato plants were observed in the treatment plot compared with the control plot ($P < 0.1$). The population densities of TPW moths and larvae increased over time during the study in the control plot (Fig. 1A, B) although all collected larvae were removed from subplots. The mean number of males collected in the pheromone traps reached a peak of 4.0 moths per trap per week on 14 June, and mean number of larvae per plant reached a peak of 0.33 two weeks later. The percentage of infested plants was as high as 40% in the control plot by the end of June (Fig. 1C).

In contrast, the mean number of moths collected by the pheromone traps in the treatment plot was reduced from 0.6 per trap per week on 23 March to zero by five weeks after application of mating disruptant. No moths were collected from 27 April through 28 June, and only 0.12 larvae per plant were observed on 21 June in the treatment plot. The percentage of infested plants in the treatment plot never exceeded 1%.

TABLE I. Mean numbers (± SE) of TPW adults collected per TPW pheromone trap per week and of larvae per surveyed plant per week, and percentage of infested plants by TPW larvae per week between treatment and control plots in a commercial greenhouse operation (23 March - 28 June 1995).

Block	n	Mean no. of adults/trap/week	Mean no. of larvae/plant/week	Mean % infested plants/week
Treatment	14	0.07 ± 0.05[a]	0.01 ± 0.01	0.07 ± 0.04
Control	14	0.89 ± 0.35	0.07 ± 0.03	5.17 ± 2.90

[a] Means are significantly different between treatment and control plots (LSD test at $P < 0.05$). Data were arcsine or square root transformed before ANOVA. Untransformed data are presented in the table.

Discussion

TPW is not known to have a diapausing stage. However, TPW has been shown to overwinter in northern California in cages when tomato plants were left undisturbed after the crop season (Batiste *et al.* 1970). The normal practice is to destroy the tomato plants after harvest. The developmental threshold for the immature stages has been estimated as 9.5 to 11.4°C (Weinberg and Lange 1980; Lin

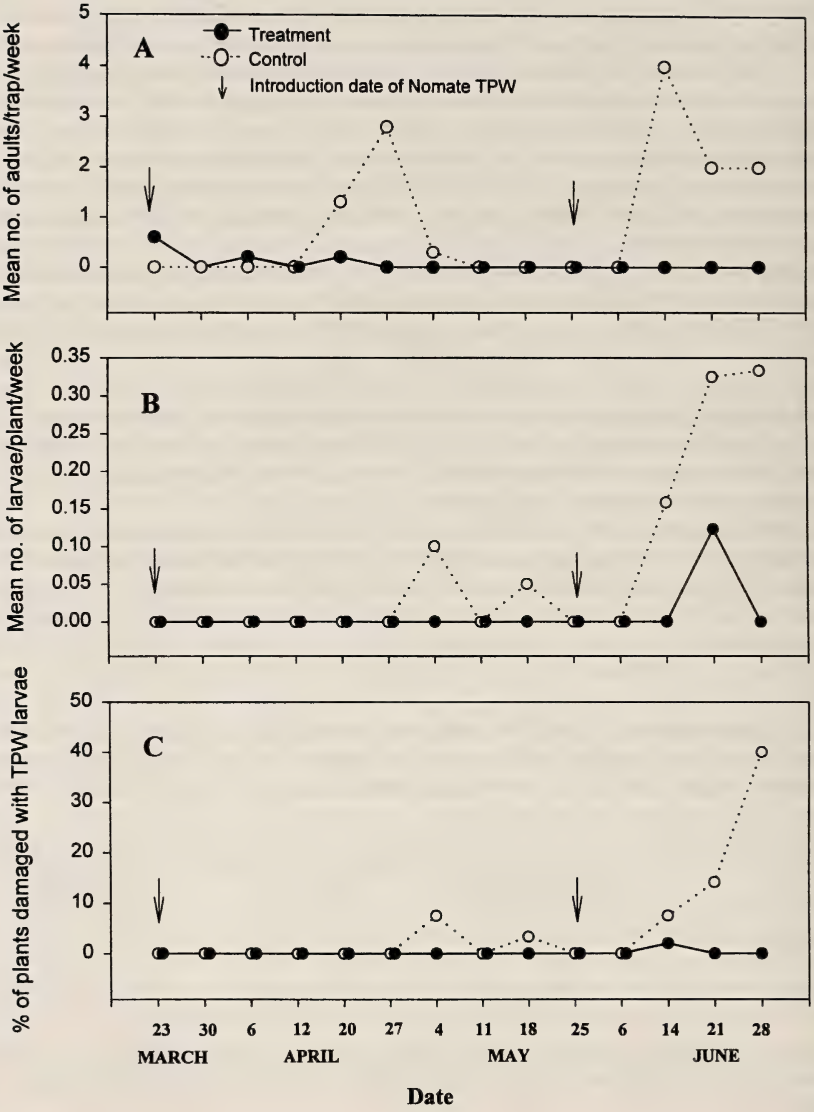

FIGURE 1. Comparison of mean number of collected adult males per trap per week (A), mean number of larvae per plant per week (B) and percentage of infested plants by TPW larvae per week (C) between treatment and control plots.

and Trumble 1985). Therefore, the chance that this species would become established in the field in Essex County is negligible. It is possible that TPW could become established in the greenhouses if crop clean-up does not eradicate all adults. The time between tomato crops is only a couple of weeks or even less due to the increased adoption of hydroponic growing techniques. In the summer, TPW can escape to the outdoors and multiply in field tomato crops. This explanation may explain the spread of the pest from the northeastern region of the survey area to the western portion during 1995. The close proximity of the greenhouses suggests also the possibility that moths could easily disperse among greenhouses on wind currents.

The source of the initial infestation of TPW in the Leamington area is probably infested tomato plants that were brought from the southern States as transplants for field tomatoes. This has been the most common method of dissemination of TPW from the southern to the northern States in the USA (Bastiste *et al.* 1970).

During the mating disruption trial, the infestation level for TPW was low in both treatment and control plots. The significant reduction in male catch and in the infestation level in the treatment plot have demonstrated that when the population density of TPW is initially low, mating disruption is an effective way to suppress this pest. It is important to remember that all detected larval infestations were removed during this trial and, as a result, probably assisted in preventing any build-up of the pest population and fruit damage.

However, the suppression effect of mating disruption may be different when the population density of TPW is moderate or high. Van Steenwyk and Oatman (1983) reported that although pheromone trap captures were reduced by *ca.* 98% with the use of mating disruption, the percentage of infested fruit was reduced by only *ca.* 25% when compared with the control. During this study, the population density of TPW was *ca.* 40 moths per trap per night in the control, too high for mating disruption to provide economical control of TPW. In this case, other measures, such as parasitoids or pesticides, must be integrated with mating disruption to achieve effective control.

In general, mating disruption is a desirable method for suppressing population densities of TPW in the greenhouse along with cultural control practices such as removal of infested plant material. This control strategy is compatible with the use of biological control agents for other pests, such as *Encarsia formosa* (Gahan) for control of greenhouse whitefly. Also, the mating disruption technique does not interfere with the use of bumble bees for crop pollination.

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EVALUATION OF BARIUM METABORATE MONOHYDRATE AND 2-(THIOCYANOMETHYLTHIO)-BENZOTHIOAZOLE AS POTENTIAL BAIT TOXICANTS OR FEEDING INHIBITORS AGAINST SUBTERRANEAN TERMITES

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A commercial form of modified barium metaborate monohydrate (Busan 11-M1, Buckman Laboratories, Inc.) and two commercial formulations of 2-(thiocyanomethylthio)-benzothiazole (TCMTB-60 and TCMTB-DM, Buckman Laboratories, Inc.), as well as the solvents of the latter two, methyl carbitol and DMATO, respectively, were evaluated as anti-termitic agents against the eastern subterranean termite, *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae). The materials were applied at concentrations of 100,000, 50,000, 10,000, and 5,000 ppm to cardboard rolls. Under choice-feeding conditions, none of the materials or solvents induced significant mortality indicating a lack of potential as bait toxicants. All materials, except methyl carbitol, did inhibit feeding at most concentrations, but none of the materials totally prevented feeding even at the highest concentration indicating a lack of strong repellency. Therefore, Busan 11-M1, TCMTB-60, TCMTB-DM, and DMATO appear to depress feeding preference and could have some utility as product additives to deter termite feeding.

Introduction

Recently, new strategies for termite control have been developed which use minute quantities of toxic chemicals (Myles and Grace 1991; Myles 1992; Myles *et al.* 1994; Myles 1996; Forschler 1996; Pawson and Gold 1996) or non-chemical means (Myles 1992; Myles in press; Grace *et al.* 1996; Lewis *et al.* 1996). Because of the diversity of termites and the diversity of man-made structures and products which require protection from termites there are needs for diverse control strategies and diverse anti-termitic compounds (Grace 1988; 1990; Myles 1994; Gold *et al.* 1996).

Different termiticides are required for different types of termite pests, dry wood or subterranean, and for different control strategies. Specific chemical and physical characteristics are required depending on the specific use. The major categories of anti-termitic agents and their respective attributes can be listed as: 1) compounds to be used as soil termiticides should have long residual action in various soil types, 2) materials to be used as wood preservatives should have high retention and low leachability in wood, 3) dry-wood termite fumigants should have high penetrability and low chemical reactivity, 4) topical transmissible toxicants should be non-irritating topically and highly transmissible via grooming and trophallaxis, 5) bait toxicants should have a concentration range at which they are both non-repellent and toxic, and 6) synthetic product additives should be stable with the product and deter termite feeding. The objective of the present study was to evaluate the potential use of selected materials as potential anti-termitic bait toxicants or product additives.

Materials and Methods

Five materials were evaluated. These included a commercial form of modified barium metaborate monohydrate (Busan 11-M1) and two commercial formulations of 2-(thiocyanomethylthio)-benzothiazole (TCMTB-60 and TCMTB-DM), as well as the solvents of the latter two, methyl carbitol (diethylene glycol monomethyl ether) and DMATO (a proprietary solvent), respectively (all products of Buckman Laboratories, Inc.). The materials were applied by pipette in acetone solutions to cardboard rolls at concentrations of 100,000, 50,000, 10,000, 5,000 and 0 ppm (net loading, wt:wt) and allowed to dry in a fume hood overnight. There were three replicates for each concentration of each material. Each replicate had 500 *Reticulitermes flavipes* termites, all from the same colony collected in Toronto.

Each bioassay unit consisted of a 400 ml plastic cup (Dixie Styroware 14G) about half-filled with 300 g moist brick sand. Each had an untreated and a treated roll so that the materials were presented to the termites under choice-feeding conditions. The soil moisture was maintained at water saturation minus 7% as according to the American Society of Testing Materials (ASTM: D 3345-74(80)) = 52.5 ml. This moisture level was maintained by weighing each cup weekly and replacing by pipet the amount lost by evaporation.

The treated and untreated cardboard was rolled into small rolls measuring three centimetres in diameter by five centimetres in length. Each roll was held in a spirally wound configuration by a loop of copper wire. The end of the wire was then inserted into the soil of the bioassay unit so that the roll just touched the soil surface. This provided adequate access for the termites to the rolls while preventing moisture in the soil from wetting the roll and diffusing the test material. The termites were added immediately after the rolls so that no prior tunnelling would bias access to one or the other of the rolls.

The bioassay units were kept on laboratory bench tops under ambient lab conditions (*ca.* 20°C, 60% RH) for the duration of the test, and were dismantled after 61 days. The surviving termites were counted, and the cardboard was cleaned by brushing off any adhering sand, oven-dried to stable weight, and re-weighed to calculate cardboard consumption for each roll.

Data were analyzed by ANOVA procedures run with CoHort Software (CoStat Ver. 4.1). The percent mortality data were transformed using the angular transformation (arcsin of square root) (Sokal and Rohlf 1981). A one-way completely randomized model was used to compare mortality means among concentrations for each material. Comparison of summed consumption (the treated plus the untreated roll for each replicate) was also by a one-way completely randomized model among concentrations for each material. Paired tests (T Method) were used to compare consumption between the treated and untreated rolls for each concentration of each material. Pooled consumption for all concentrations of each material was compared to pooled consumption of untreated rolls, also by the one-way completely randomized model. Tukey's Honestly Significant Difference was used as the means test at a significance level of 0.05.

Results and Discussion

Mortality. Mortality in the controls was higher than expected, probably due to the two-month rather than the usual one-month duration of the experiment (ASTM 1974). Another possible cause of control mortality could be that the source colony may have been less vigorous than usual. None of the treatments at any concentration induced significant mortality above control levels (Table I).

Consumption. For all the controls (0 ppm) there were no significant differences in the paired consumption tests indicating that the acetone alone had no effect on cardboard consumption. In contrast, all materials, except methyl carbitol, appeared to inhibit feeding as indicated by the paired

TABLE I. Termite mortality and cardboard consumption in choice-feeding bioassays.

Material	Conc. (ppm)	Mort. (%) Ave.±S.E.[1]	Consumption (mg)		
			Treated	Untreated[2]	Sum±S.E.[1]
Busan 11-M1	100,000	73.2±12.5a	197.0	563.7 *	760.7±117.7a
	50,000	54.5± 8.5a	121.8	524.6 *	646.4±116.5a
	10,000	50.2± 3.7a	146.8	582.3 ns	729.1±172.0a
	5,000	52.0± 8.9a	208.1	544.6 *	752.7± 21.1a
	0	61.6±19.3a	328.6	403.1 ns	731.7± 57.6a
TCMTB-60	100,000	49.6± 4.2a	312.2	500.9 ns	813.1± 79.7a
	50,000	43.9± 3.5a	147.5	683.4 ***	830.9± 35.9a
	10,000	41.2± 0.9a	87.0	598.4 *	685.4±139.4a
	5,000	41.1± 3.7a	125.7	664.6 **	790.3± 84.9a
	0	36.1± 3.9a	166.5	439.6 ns	606.1± 18.6a
TCMTB-DM	100,000	40.0± 3.7a	142.9	547.3 ***	690.2± 54.7a
	50,000	40.6± 4.1a	116.4	610.5 *	726.9±124.3a
	10,000	43.7± 2.1a	120.0	428.7 **	548.7± 18.0ab
	5,000	38.6±20.1a	91.8	522.8 ***	614.6± 34.3ab
	0	36.1± 5.9a	80.1	258.2 ns	338.3± 66.1b
DMATO	100,000	52.3± 6.6a	121.2	582.2 **	703.4±104.9a
	50,000	48.9± 1.2a	235.8	200.4 ns	436.2±145.2a
	10,000	47.5± 8.1a	158.0	418.1 *	576.1± 69.8a
	5,000	42.9± 2.6a	59.7	442.2 ***	501.9± 35.9a
	0	51.1± 6.6a	316.6	197.6 ns	514.2± 77.9a
Methyl Carb.	100,000	52.6± 3.0a	380.8	263.8 ns	644.6±101.2a
	50,000	46.5± 5.2a	268.5	344.6 ns	613.1± 77.9a
	10,000	41.7± 1.9a	309.5	215.9 ns	525.4± 12.1a
	5,000	44.7± 1.3a	230.4	318.7 ns	549.1± 32.0a
	0	42.1± 1.9a	188.1	193.3 ns	381.4±137.6a

[1] Within a given chemical, values sharing the same letter are not statistically different at the 0.05 level.

[2] * $P<0.05$, ** $P<0.01$, *** $P<0.005$

tests of consumption between the treated and untreated rolls at the lowest concentration, 5,000 ppm (Table I). However, a few of the paired tests indicated non-significant differences at some concentration above 5,000 ppm , *e.g.*, 10,000 ppm for Busan 11-M1, 100,000 ppm for TCMTB-60, and 50,000 ppm for DMATO. For the 10,000 ppm Busan 11-M1 treatment, although there was a strong difference in the average consumption between the treated and untreated cardboard, the statistical test indicated a non-significance due to large variation among replicates, but the p value was actually close to the 5% significance level at 0.081. Since consumption differences were significant at both higher and lower concentrations, the trend of the data suggests that this anomaly was a type I statistical error (Sokal and Rohlf 1981). The p values were not as close for the other two cases but these are also best explained as type 1 errors since lower concentrations showed highly significant differences. When the data for all concentrations were pooled, the reduced consumption of treated cardboard compared to the untreated cardboard, was highly significant for Busan 11-M1, TCMTB-60, TCMTB-DM and DMATO. Methyl carbitol did not inhibit feeding at any concentration. No significant depression of total consumption was induced by any of the materials. In fact the only significant difference in total consumption was seen in TCMTB-DM in which there was actually less feeding in the control than at the 50,000 and 100,000 ppm concentrations. The absence of any significant depression in total consumption indicates that the termites chose to avoid feeding on the treated rolls in preference to the untreated rolls. It is interesting to note, however, that feeding did occur on all of the treated rolls and that the feeding depression showed no clear dose relationship.

Potential as Anti-termitic Compounds. The absence of significant induced mortality under choice-feeding suggests that none of the materials has good bait potential. These results differ from those reported by Grace (1988, 1990) in which significant mortality was reported with TCMTB after forced-feeding at 10,000 and 50,000 ppm; and significant mortality was reported with Busan 11-M1 after forced-feeding at or above 10,000 ppm. These differences are not surprising since the present study was under choice-feeding conditions. Choice-feeding conditions reflect the condition under which baits would have to work in the field.

The failure of any material to totally prevent feeding indicates that none of the materials acts as a strong termite repellent. However Busan 11-M1, TCMTB-60, TCMTB-DM, and DMATO all appear to depress feeding preference at the lowest concentration tested, 5,000 ppm. They may therefore have potential as anti-termitic product additives. However, since feeding was not completely suppressed, slight surface feeding on the product (cosmetic damage) might occur.

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EUROPEAN RED MITE (*PANONYCHUS ULMI* KOCH): A NEW PROBLEM IN ONTARIO VINEYARDS

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The European red mite, *Panonychus ulmi* Koch, is a major pest in apple and peach orchards of southern Ontario. Although recorded in low densities elsewhere in Canada (Madsen and Morgan 1975), high densities of *P. ulmi* have not previously been observed in vineyards. However, *P. ulmi* is problematic in vineyards of other areas including France, Switzerland and Italy (Bouron 1988; Engel and Ohnesorge 1994). Here we document high *P. ulmi* densities in southern Ontario vineyards.

We sampled *P. ulmi* from nine representative vineyards in the Niagara region, southern Ontario. In each vineyard four ten-leaf samples were randomly taken from 'Chardonnay' variety vines in late August, 1996. Leaves were taken from separate plants. In the laboratory, mites were brushed from the leaves onto a glass plate using a Henderson-McBurnie mite brushing machine, and examined using a binocular microscope. For *P. ulmi* and phytoseiid mite species, egg and motile stages were counted and combined to give one density estimate per leaf, for each taxon.

P. ulmi were found in each vineyard, at densities from 5.65 to 320 per leaf (Table I). In Europe the economic threshold for *P. ulmi* in vineyards is presently 2-5 mites per leaf (Boller and Remund 1983; Schruft *et al.* 1990, cited in Candolfi *et al.* 1993). In this study, all vineyards had densities higher than 5 *P. ulmi* per leaf, and some managers reported some vine leaf-bronzing in a range of varieties, most likely resulting from mite feeding. Most owners indicated they had observed *P. ulmi* becoming more prolific in recent years.

To determine if the *P. ulmi* outbreaks occurred on varieties other than the 'Chardonnay' variety, in vineyard B and C, four ten-leaf samples were taken from 5 varieties: 'Cabernet Franc', 'Cabernet Sauvignon', 'Chardonnay', 'Concord' and 'Riesling'. In vineyard B the variety with the highest density of *P. ulmi* was 'Cabernet Franc' with a mean of 129 ± 15.0 (standard error) per leaf, followed by 'Concord' (105 ± 29.4), 'Chardonnay' (78.4 ± 40.4), 'Cabernet Sauvignon' (72.0 ± 9.54), and 'Reisling' (59.9 ± 34.7). In vineyard C the variety with the highest density of *P. ulmi* was 'Chardonnay' with a mean of 235 ± 47.2 per leaf, followed by 'Reisling' (114 ± 8.26), 'Concord' (45.4 ± 8.13), 'Cabernet Franc' (6.15 ± 1.35), and 'Cabernet Sauvignon' (6.10 ± 2.86). Phytoseiid mites were found in all but two vineyards, in densities from 0.10 to 3.3 per leaf. Of the 177 phytoseiid mites examined 71% were identified as *Typhlodromus pyri* Scheuten, 17% were *Amblyseius fallacis* (Garman), 9% were *Typhlodromus caudiglans* (Schuster), and 3% were *Amblyseius andersoni* (Chant).

In vineyards elsewhere, *P. ulmi* is generally controlled below economic thresholds by acarine predation (Rambier 1972). It is considered an induced pest, as the use of pesticides can result in a *P. ulmi* outbreak. *Typhlodromus pyri* is the major phytoseiid predator limiting *P. ulmi* densities in European vineyards (Engel and Ohnesorge 1994), though was obviously unable to control *P. ulmi* densities here. Predators may be affected by chemical sprays, which include captan, dinocap, mancozeb, metalaxyl, and sulphur. Sulphurous fungicides have been associated with *P. ulmi* outbreaks in some vineyards in Italy (Duso 1988), and can reduce phytoseiid mite densities (Schwartz 1993). The only insecticides sprayed on the vineyards studied here were Dicofol and Diazinon. In nearby orchards

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TABLE I. *Panonychus ulmi* and phytoseiid densities (mites per leaf; n= 4 samples of 10 leaves) of samples taken from Chardonnay variety vines, in vineyards in Niagara-on-the-Lake and Vineland regions. SE = standard error.

Region and vineyard	*P. ulmi*		Phytoseiid		Phytoseiid species[1]
	Mean	SE	Mean	SE	
Vineland					
Vineyard A	320	5.30	0.367	0.228	*A. fallacis*
Vineyard B	78.4	40.4	0.500	0.167	*T. pyri, A. fallacis, T. caudiglans*
Vineyard C[2]	235	47.2	0.458	0.188	*T. pyri, A. fallacis, T. caudiglans*
Vineyard D[2,3]	9.68	0.88	0.000	0.000	-
Niagara-on-the-Lake					
Vineyard E	9.43	0.931	0.33	0.139	*T. caudiglans*
Vineyard F	249	2.83	0.367	0.227	*A. fallacis, T. caudiglans*
Vineyard H	66.3	1.53	0.067	0.112	*A. fallacis*
Vineyard I	4.93	0.72	0.425	0.268	*T. caudiglans, A. andersoni*
Vineyard J[1]	5.65	0.84	0.000	0.000	-

[1] Phytoseiids species are presented in order of abundance for each vineyard

[2] Sprayed with the insecticide Dicofol within one week prior to sampling

[3] Riesling variety next to the Chardonnay had approximately 274 *P. ulmi* per leaf

P. ulmi has developed resistance to Dicofol (Mable and Pree 1992), while predators may well be susceptible (Thistlewood and Marshall, unpublished data).

Densities of *P. ulmi* reported here were up to 64x the economic threshold for *P. ulmi* in the vineyards of Europe. Hence it is highly likely that economic damage is being incurred on a range of varieties in Ontario vineyards by *P. ulmi*. Work is in progress to elucidate causative factors, and methods for the control of *P. ulmi* outbreaks.

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OPTIMAL RELEASE RATE OF THE HOST MONOTERPENE α-PINENE FOR TRAPPING THE EUROPEAN PINE SHOOT BEETLE, *TOMICUS PINIPERDA* (COLEOPTERA: SCOLYTIDAE)

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Many scolytid beetles native to Europe and elsewhere have been intercepted at North American ports, and some of these have become established (Haack *et al.* 1997). The larger European pine shoot beetle, *Tomicus piniperda* (L.), was discovered near Cleveland, Ohio, in 1992 (Haack 1997), and is now found in eight US states around the Great Lakes, as well as in southern Ontario.

The flight of *T. piniperda* is earlier than native bark beetle species, and usually of extremely short duration (Långström 1983; Haack and Lawrence 1995). Its ability to breed in numerous North American pine species (Lawrence and Haack 1995; Haack and Lawrence 1997), and the potentially serious economic impact on Scots pine (*Pinus sylvestris* L.) Christmas tree nurseries in the Great Lakes area, has led to a considerable effort in delineating and limiting the spread of this insect (Haack 1997). Consequently, subsequent to the initial discovery of the insect, a primary objective was to quickly implement detection techniques in order to identify areas where the beetles had become established. At the request of the US Department of Agriculture (USDA), Agricultural Plant Health Inspection Service (APHIS), I recommended the use of a lure releasing α-pinene at 300 mg/24 h @ 24°C. The recommendation was primarily based on data from Schroeder and Lindelöw (1989), who found increasing catches with release rate up to their maximum rate of about 250 mg/24 h. The objective of this study was to determine if the recommended release rate was optimal for trapping *T. piniperda* adults, and whether or not increased sensitivity of detection traps would be possible with higher release rates than those used by Schroeder and Lindelöw (1989).

The study was conducted 20-29 April, 1993, in two pre-commercially thinned stands of Scots pine, 3 km north of Ålands Kyrka, about 25 km west of Uppsala, Sweden. Nine 12-unit Lindgren funnel traps (Lindgren 1983; Phero Tech Inc., Delta, BC) were set up in each of the two stands, which were separated by about 1 km. In each stand, traps were assigned to three completely randomized blocks, each consisting of a row of three traps. Traps within and between blocks within a stand were separated by a minimum of 20 m. Three treatments, consisting of 1, 2, or 3 α-pinene release devices, were randomly assigned to traps within a block. Each release device consisted of a 15 ml low density polyethylene bottle with screw cap releasing the monoterpene at about 150 mg/24 h @ 24°C. Thus, the 2-device treatment corresponded to the recommended monitoring lure. The α-pinene was obtained from Fluka Chemicals (Gillingham, Dorset, United Kingdom), and had a chemical purity of 98.7%, consisting of 85% of the (-)- and 15% of the (+)-enantiomer. The traps were emptied on 23 and 29 April, and the beetles were taken back to the lab and counted. The data were transformed as $x'=\log_{10}(x+1)$ to correct for heterogeneity of variances. The transformed data were analysed by analysis of variance, followed by mean separation by Tukey's test using SYSTAT (Wilkinson 1990).

A total of 356 *T. piniperda* were captured in the α-pinene-baited traps. In addition, 78 *Hylurgops palliatus* (Gyll.), a secondary bark beetle which breeds in Scots pine and Norway spruce, *Picea abies* (L.) Karst., various Coleoptera, e.g. Cleridae, Staphylinidae, Curculionidae and other Scolytidae, were caught in very low numbers. The results show that *T. piniperda* responds optimally to α-pinene

TABLE I. Mean catch (± 1 SD) of *Tomicus piniperda* to three release rates of α-pinene in Lindgren funnel traps (N=6 traps per release rate). Ålands Kyrka, Sweden, April 20-29, 1993.

α-Pinene Release Rate (mg/24 h @ 24°C)	Mean Catch ± 1 SD[1]
150	9.0 ± 4.8a
300	23.0 ± 2.8b
450	27.3 ±11.1b

[1] Means within columns followed by the same letter are not significantly different, analysis of variance (α=0.05) followed by Tukey's procedure for mean separation.

released at 300 mg/24 h, which caught significantly more *T. piniperda* than traps baited with the 150 mg/24 h rate, but not significantly different numbers than the 450 mg/24 h rate (Table I). For *H. palliatus* the treatments were not significantly different from each other, possibly due to relatively higher variance in the catches.

Schroeder and Lindelöw (1989) investigated the effects on several species of bark beetles of α-pinene and ethanol in different relative and absolute amounts. Their data clearly show a dose response by *T. piniperda* to α-pinene, with or without ethanol. However, they tested α-pinene in the range of 0 to 250 mg/24 h, leaving the possibility that even higher doses would be optimal. They also used flight barrier, or window traps rather than traps with a vertical, tree trunk-simulating profile such as the Lindgren funnel trap used in this study. Different trap types may affect how bark beetle respond to pheromones and kairomones.

My data confirm that the α-pinene release rate recommended to the USDA is optimal for monitoring *T. piniperda* in Lindgren funnel traps. The applicability of these results to monitoring of *T. piniperda* in North America were confirmed by similar results obtained in Michigan (summarized by Haack *et al.* 1997).

In the absence of an aggregation pheromone for *T. piniperda* the use of α-pinene-baited traps provides a simple, inexpensive, and relatively effective means for monitoring and detection of this exotic scolytid species. While the addition of ethanol has been suggested to enhance attraction (Schroeder and Lindelöw 1989), α-pinene alone may be more selective, since numerous xylophagous species respond to ethanol alone or in combination with α-pinene (Montgomery and Wargo 1983). Selectivity is important in detection trapping, since it means reduced costs associated with sorting and identification.

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COTESIA RUBECULA (MARSHALL) (HYMENOPTERA: BRACONIDAE) RECOVERED THREE YEARS AFTER RELEASE IN SOUTHERN ONTARIO

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Cotesia rubecula (Marshall) is a braconid endoparasitoid of the imported cabbageworm, *Pieris rapae* (L.), a common pest of cole crops in North America. *C. rubecula* has been used in classical biological control programs in Australia and China (Nealis 1985) and in the United States (Puttler *et al.* 1970; McDonald and Kok 1992). A strain of *C. rubecula* from Yugoslavia was released in southern Ontario from 1978 to 1983 but failed to overwinter and did not become established (Laing and Corrigan 1987); however, *C. rubecula* was found in the Ottawa area ten years after being released there (Corrigan 1982). Further attempts at establishment of a Chinese strain of *C. rubecula* were made at the Cambridge Research Station, Cambridge, Ontario in the summers of 1991 and 1992.

A colony of *C. rubecula* was started at the Biological Control Laboratory, University of Guelph, Guelph, Ontario from cocoons imported from Beijing, People's Republic of China, via Massachusetts. From this colony, approximately 2800 parasitized hosts and 44 adult wasps were released in 1991. The following spring, 16 unopened cocoons were recovered from 6 May - 22 May 1992. A male *C. rubecula* emerged from one cocoon, hyperparasites (*Catolaccus* sp. [Hymenoptera: Pteromalidae] and *Mesochorus vittator* (Zetterstedt) [Hymenoptera: Ichneumonidae], identified by Dr. G. Gibson and Dr. J. Barron, Centre for Land and Biological Resources Research, Ottawa, Ontario) emerged from two other cocoons and 13 cocoons contained dead *C. rubecula* (three pupae and ten adults). In addition, a female *C. rubecula* emerged from a cocoon found in casual examination of cabbage plants on 18 August 1992. No releases had been made in 1992 at the Cambridge Research Station prior to 18 August, but 142 adults and 23 cocoons were released later that month. No releases of *C. rubecula* were made at the Cambridge Research Station in 1993 or 1994.

Three times during the fall of 1993, the release plot and nearby fields of cabbage were searched, and cocoons of *C. rubecula* were found on each occasion. Five female and two male *C. rubecula* emerged from seven of the 15 occupied cocoons found in the field in 1993, and one cocoon contained a dead larval *C. rubecula. Baryscapus (=Tetrastichus) galactopus* (Ratzeburg) (identified by Dr. J. Huber, Centre for Land and Biological Resources Research, Ottawa, Ontario), a hyperparasite of *C. rubecula*, emerged from the remaining seven cocoons.

Parker *et al.* (1971) reported rates of hyperparasitism of *C. rubecula* by *Tetrastichus galactopus* from 36.6% to 72.4% in Missouri while Nealis (1983) reported hyperparasitism rates of 62% in 1981 and 41% in 1982 in British Columbia. Nealis (1983) did not believe that the sizeable losses of *C. rubecula* in British Columbia due to hyperparasitism severely affected the established population of parasitoids, nor did Parker *et al.* (1971), although *C. rubecula* did not become established in Missouri. McDonald and Kok (1992) suggested that hyperparasites, especially *Spilochalcis torvina* (Cresson) [Hymenoptera: Chalcididae], were a limiting factor in the establishment of *C. rubecula* in southwestern Virginia. In southern Ontario, hyperparasites, especially *B. galactopus*, may also be a limiting factor in the establishment of *C. rubecula*. This conclusion is based on a small sample of recovered cocoons

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of *C. rubecula*, so although hyperparasitism is a mortality factor for *C. rubecula*, the true level of hyperparasitism is unknown.

Two years after the last release, cocoons of *C. rubecula* were again found at the Cambridge Research Station on 29 July 1994. A plot of cabbage and broccoli at the release site provided overwintering refuge for *C. rubecula*, until it was plowed on 4 May 1994. Cole crops were not replanted in that area in 1994. A total of eleven cocoons were found in three separate 100 m^2 plots of cabbage at the research farm. Nine cocoons were recovered in a plot approximately 100 m from the original release site. Six female *C. rubecula* emerged from the cocoons, and hyperparasites (*B. galactopus*) emerged from two cocoons. Nothing emerged from the remaining cocoon, which, when dissected, contained a desiccated pupal *C. rubecula*. Two cocoons, one yielding a male, the other a female *C. rubecula* were found in plots approximately 200 m and 300 m from the release site.

No overwintering refuge crops were left in the research station area during the winter of 1994 - 1995. On 8 September 1995, a preliminary check for *C. rubecula* cocoons was made on 50 broccoli and 50 cabbage plants approximately 300 - 400 m from the original release site: 64% of plants were found to have at least one *C. rubecula* cocoon on them.

On 12 September 1995, 60 intact *C. rubecula* cocoons and 18 empty *C. rubecula* cocoons were recovered from only 25 cabbage plants in the same area and every plant had at least one *C. rubecula* cocoon. Only a single mass of *Cotesia glomerata* cocoons was recovered from the same 25 plants. Of 91 healthy larval *P. rapae* also collected from these plants, 44% died later in the lab and 41% successfully pupated. *C. rubecula* emerged from 15% of the larval *P. rapae*. On 13 September 1995, 65 intact *C. rubecula* cocoons and 23 empty *C. rubecula* cocoons were recovered from 25 broccoli plants. In this case 88% of the plants had cocoons on them and only five *C. glomerata* cocoon masses were found. From the 25 broccoli plants, 206 larval *P. rapae* were recovered and reared in the lab with the results that 31% died and 46% pupated. In addition, *C. rubecula* emerged from 21% and *C. glomerata* emerged from 1% of the larval *P. rapae*.

Thus, three years after the last release of *C. rubecula* and without the benefit of refuge plots of cole crops in which to overwinter in 1994 - 1995, the parasitoids were still present in the area. Monitoring in future years will determine if *C. rubecula* is able to maintain its establishment in this part of southern Ontario.

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BOOK REVIEWS

Insects of Algonquin Provincial Park 1997 *by* S. Marshall, The Friends of Algonquin Park, Whitney, Ontario, Canada. 48 pp. ISBN 1-895709-36-9. $2.95 CAN

This is another volume in the expanding series of books dealing with the plants and animals found in Algonquin Provincial Park, a popular vacation and research site for tourists and scientists from across the province and neighbouring areas. The book takes on an enormous task; unlike the authors of previous volumes on trees, fish or mammals for example, not all of the subject organisms can be presented in one thin book. The author explains this in the first paragraph of the book, and states that the intention of the book is to serve as an overview of the insects of the park, and to illustrate and describe the most common and some of the more interesting insects that have been found within park boundaries.

The first section is a concise synopsis of insect morphology, life cycles, how to identify insects, and short descriptions of the major orders. Included in this section is a hierarchical picture-key to the most common orders of winged insects, one I recognize from having taken the author's courses at the University of Guelph. The key works very well; I recently used it with ecology students during a laboratory field module, and students not previously exposed to insect identification could easily identify the order of insects presented to them.

The rest of the book follows the format of the earlier volumes: it is divided into sections dealing with specific situations such as habitat type (*e.g.* roadside, water surface, boggy areas), behaviour (*e.g.* stinging insects, biting flies) or ecology (*e.g.* parasitism, pollination, plant-insect interactions). My personal favourite section is "Life in the Dead Zone — Insects of Dung and Carrion". I have never seen so many synonyms for shit before; this section highlights the author's ability to inform and entertain at the same time, something not easily done. In all, I found it very readable and written in a manner that is suitable for both the inexperienced nature lover and the trained scientist. The teaching entomologist would enjoy it for its instructional value — it is a good source of basic insect natural history, something that is sorely lacking in the common entomology textbooks and usual identification guides.

The photographs are to marvel at. All (except one — and I'll let the reader find it, bearing in mind that I had to be very critical to find it myself) are crisp and clear, and well composed to the point of being artistic. The author is an exceptional and prolific insect photographer, traits which are obvious from this book.

As in every publication, there are the unavoidable typos and a few spelling errors, but on the whole it is an excellent little book. Although specifically written for the average park visitor, it would be informative to anyone with even a passing interest in insects. If you go to Algonquin, be sure to pick one up. If you teach entomology or zoology, you may find it useful as additional or introductory reading for your students, or even a source of some natural history knowledge that you didn't know yourself.

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Evolutionary Ecology Across Three Trophic Levels: Goldenrods, Gallmakers, and Natural Enemies 1997 *by* Warren G. Abrahamson and Arthur E. Weis, Princeton University Press, Princeton, N.J. XIII + 456 pp. ISBN: 0-691-01208-3. Paper. $29.95 US

Goldenrods are dominant members of the fall-blooming flora of Ontario, and are common in old fields, roadsides and other disturbed areas. Generations of students have "learned their insects" by observing and collecting on goldenrod. The herbivore fauna of goldenrods includes over 100 species (Messina and Root 1980), and the flowers are an important late-season nectar source for many insects, including migrating monarch butterflies. In addition, the plants provide a focus for the activities for many predators and parasitoids. In the parlance of conservation biology, the more common species of goldenrod can be regarded as "keystone species", species that have a disproportionately large impact on their communities because of both trophic position and interactions with other species (Meffe and Carroll 1997). On face value, a book summarizing the ecology and natural history of goldenrods and their gallmakers would seem to be a worthwhile addition to the library of most entomologists in Ontario. For better or for worse, the scope of the book is more restrictive.

Firstly, the subtitle is a little misleading. I was expecting a treatment of all of the gallmakers found on goldenrod. In fact, the book really only deals with the goldenrod gall fly, *Eurosta solidaginis* (Diptera: Tephritidae). The two common spindle gallmakers, *Gnorimoschema gallaesolidaginis* and *Epiblema scudderiana* (Lepidoptera) are treated only in passing. This book is more concerned with evolutionary ecology and population genetics than with the gall fly-goldenrod community — or the "system". This focus on theory is not unexpected, given that this is number 29 in the Monographs in Population Biology series, which has included such important contributions to evolutionary biology as *The Theory of Island Biogeography* (#31; MacArthur and Wilson 1967) and ***Natural Selection in the Wild*** (#21; Endler 1986). This is not a criticism — only a warning. This is certainly not a "quick read" but a challenging journey into the intricacies and nuances of evolutionary biology, summarizing as it does almost 25 years of research by the authors and collaborators published in such front line journals as *Evolution*, *American Naturalist*, and *Ecology*. The "data intense" nature of the book is evidenced by the 140 included figures and tables, many from the original journal articles.

The first chapter is a useful introduction to the book, outlining the topics covered in each of the chapters. The second chapter presents the natural history of the "system" and is almost certainly where most readers will gravitate. Unfortunately, this is perhaps the weakest chapter of the book. The biology of the interacting species is clearly laid out but I cannot help but wondering if taxonomic uncertainties complicate the issue. The taxonomy of *Solidago* is, as the authors note, "complicated and as yet unresolved" — perhaps the situation would be clearer if they had considered the most recent taxonomic treatment of the genus (Semple 1992). And the taxonomy of the gall-maker is also suspect, based as it is on an unpublished Master's thesis! These problems persist also at the level of the natural enemies. The genus *Eurytoma* is difficult at best; the 92 Nearctic species were last reviewed over 30 years ago (DiGiulio 1997). At least, there are no problems with the identity of the two species of birds that include the gall inhabitants in their winter diet! Faced with this uncertainty, the only advice I can give to anyone working with goldenrod and its associates is to make sure you have voucher specimens. The habitus illustrations in this chapter, contrary to the claims of the authors, are not very useful. Figure 2.2 is of limited value in distinguishing between *S. altissima* and *S. gigantea*; I defy anyone to find a difference in the illustrations of the pubescence on the leaf undersides! For the insects, the photographs in Uhler (1951) are far superior. And most readers of the PESO will be amused to hear that we have an "Ontario National Museum" and that the Ontario Department of Agriculture maintains a herbarium in Ottawa. This chapter, at least, would have benefited from a careful editing.

Subsequent chapters consider questions about the interaction of the plant and its herbivore: Chapter 3, What effect does the gallmaker have on the fitness of the clonal host plant? (not much, unless population levels are very high or the plant is very young); Chapter 4, Is there genetic variation in susceptibility to galling? (there is ample genotypic variation to allow a selection response); Chapter 5, Do female gallmakers select susceptible host plants, and does this result in higher performance of their offspring?(they do but it doesn't help the offspring due to a lack of correlation of female oviposition preference and offspring success); Chapter 6, Does the gallmaker or the plant or both make genetic contributions to gall size? (mainly the gallmaker); Chapter 7, Is the gallmaker divided into host-associated populations, and is there the possibility of sympatric speciation? (apparently so, near the northern edge of S. *altissima's* range where the gallmaker is sympatric on *S. gigantea*). The next two chapters add the third trophic level. Chapters 8 and 9 concern the natural enemies, parasitoids and insectivorous birds. This chapter makes the startling claim that since the parasitoids are unable to curtail the growth and development of the gall (both species of *Eurytoma* kill the host after the gall has formed) they have no beneficial effects on the goldenrod. But what about next Spring — won't there be a reduced number of gallmakers present to attack the clone as a result of the late summer/early fall parasitoid-mediated mortality? Furthermore, there is an interesting conflict in optimal gall size due to opposing selection pressures — one of the parasitoids in unable to penetrate large galls (a selection pressure for larger galls) while birds prefer large galls (a selection pressure for smaller galls). Density- and frequency-dependent selection on gall size is examined as a result of these opposing selection pressures, which differ in intensity in time and space. The final three chapters deal with broader evolutionary issues that emerge from the study of this model system. Although the authors state emphatically that "Chief among our goals has been to understand how selection has operated, or is operating, to shape key features of the goldenrod-gallmaker-natural enemy interaction", they do apparently appreciate the importance of phylogenetics in evaluating these claims. However, the cladistics is flawed in practice (notwithstanding the annoying reference to "synaporphies" (p. 31)). Their evidence for the rarity of host shifts by the gall fly from *S. altissima* to *S. gigantea* is based on UPGMA clustering of a genetic distance matrix. They overturn a phylogenetic hypothesis based on morphological data with an unpublished MtDNA data set. This is significant because the morphological data suggests that stem gallers like *Eurosta solidaginis* are plesiotypic based on outgroup analysis with the presumed sister genus whereas the MtDNA data suggests that stem galling is derived, and that diversification in *Eurosta* has proceeded through host-plant shifts. A highly corroborated phylogeny for *Eurosta* is required to evaluate their suggestions that host-race formation has occurred in the absence of geographic reproductive isolation.

So what of my original hope that the book would deal with the totality of the gallmakers associated with goldenrod? Clearly, this would be impossible. As evidenced by this book, Abrahamson and Weis have devoted a large part of their professional careers to investigating the interactions of a "simple" tritrophic level system. Now, consider the ramifications of adding on an additional two gallmakers. How would this affect the functioning of this model system? Are the fitness effects on the plant the same for the gall fly and the two spindle gallmakers? Does resistance to attack by the gall fly confer increased or decreased resistance to the spindle gallmakers. How about interactions across the third trophic level? Although the parasitoid complexes appear to be non-overlapping, both *Eurosta* galls and spindle galls are attacked by species of *Eurytoma* and birds also attack spindle galls during the winter. The point is that the extension of these studies to a community level approach would be frightfully complicated. As it stands, this book would make an ideal focus for an advanced undergraduate or graduate reading course in evolutionary biology, integrating as it does tritrophic interactions (plant, herbivore, natural enemies) from the perspective of natural selection. But I wouldn't recommend this book to naturalists or entomologists looking for a general introduction to *Solidago* and its associates.

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Floral Biology: Studies on Floral Evolution in Animal-Pollinated Plants 1996 *by* David G. Lloyd and Spencer C.H. Barrett. Chapman & Hall, New York *etc.* xiv + 410 pp.

Not for the naïve and mostly botanical, this book and its contents is one to be approached, read, and considered with care and some skepticism. Some chapters are excellent as overviews, others are more or less comprehensive accounts of the authors' studies but are incomplete as reviews and do not recognize the works of others. A few are biased and rather opinionated critiques in the guise of review and discussion. The whole volume was prepared, it is stated, in celebration of the bicentennial of Sprengel's seminal book (1793) and sprang from a symposium held at the International Botanical Congress in 1993 in Yokohama, Japan. In the preface, the book is described as "an attempt to highlight ... new synthesis that is rejuvenating the 200-year-old discipline of floral biology ..." (vii) but with the caveat that "Because of the enormous scope of contemporary research in plant reproduction, we have made no attempt to be comprehensive" (viii). This book is too incomplete to claim to be a synthesis and its rather narrow scope reflects the interests of the editors rather than "Floral Biology".

The book starts with a "Historical Perspectives" and a highly useful, and first translation of the text of Sprengel's book, well executed by Peter Haase. Only a few of the original and amazing copper plates are reproduced. It is clear that Sprengel was well ahead of his time in his thinking about form and function, a view countered by such influential biological philosophers as Goethe and the pervading adherence to special creationism. Stefan Vogel's chapter allows a good understanding of the scientific era in which Sprengel worked. After that, surprisingly little mention is made of the celebrant. Of 11 chapters, only five cite Sprengel. Of those, only two actually use specific information from Sprengel's book. The index referrals to Sprengel are incomplete, listing but three after Vogel's chapter.

Part 2 of the book, "Conceptual Issues" starts with Chapter 3 in which Carlos Herrera presents a devil's advocacy of the problems of "floral syndromes", the suites of floral features that suggest what the primary pollinators of the flowers are and how pollination would take place. The chapter should be taken *cum grano salis* even though its contentiousness, data and cautionary notes are valuable. Herrera's views not withstanding, most researchers in pollination biology treat syndromes as guide posts and are not surprised to find exceptions. The next chapter "How do Flowers Diverge?" by Wilson and Thomson presents a logical extension to the previous one. It is rather inconclusive, casting doubt on the strength of such evolutionary forces as directional selection, character displacement, while noting adaptive wandering in which selective forces vary temporally and spatially in strength and nature, correlations of suites of characters, and genetic drift. The complex interactions of those evolutionary processes is well recognized by evolutionary biologists working at the level of ecological communities, and in floral biology there are many examples besides those cited. The statement that "The interaction term pollinator species x floral morphology does not seem to have been previously of much interest to biologists ..." (101) is inaccurate because it neglects pollinator morphology and the work of zoologists working in floral biology. The discussion downplays the importance of time, environmental and biotic heterogeneity, emphasizes autecology at the expense of more relevant synecology.

Chapter 5 by Tia-Lynn Ashman and Daniel Schoen on "Floral Longevity: Fitness Consequences and Resource Costs" attempts to model why some plants have ephemeral flowers, but others have long-lived ones. There are many formulae presented to lend formality to fairly intuitively obvious relationships, but the biology is rather scant. That there are flowers that last but a single day, or less (*e.g. Cucurbita* spp., many Cactaceae, lots of tropical plants) is well known, but tends to force the model to self-support for aspects of the hypotheses being discussed, a limitation which needs more recognition. The examples used make a rather incomplete list derived from the literature. Figure 5.5 which shows the strong correlation between observed longevity and as predicted by the model seems contrived, and certainly forced by the cluster of plants with short-lived flowers. The question this chapter attempts to answer is interesting and worthy of more research, as the authors advocate.

Lawrence Harder and Spencer Barrett have written one of the best chapters in the book "Pollen Dispersal and Mating Patterns in Animal-Pollinated Plants". The models presented are theoretically sound and have been tested with real plants and pollinators. Although the chapter is mostly botanical, the roles of pollinators and their behaviours are clearly spelled out in relation to pollen carry-over from flower to flower, plant to plant, and the plant population biology through self-pollinations, outcrossing, mating systems and neighbourhood sizes, and male and female function in plants with various breeding systems. The important issues of pollinator diversity, abundance, and foraging dynamics are not so thoroughly considered even though several relevant papers have been published recently.

Geitonogamy, self-pollination within the same plant but between flowers on that plant, is not well studied. Chapter 7 by Allison Snow, Timothy Spira, Rachel Simpson, and Robert Klips presents a good overview of the subject. Pollinator behaviour is of tantamount importance in self-incompatible species, with few visits to flowers on a given plant or clone resulting in cross-pollinations. Even in self-compatible plants, geitonogamy may result in little self-fertilization. It is unfortunate that the authors did not make use of the extensive literature in crop pollination to strengthen their suites of examples and present the practical importance of their ideas.

The sizes of flowers and inflorescences are important in attracting pollinators. In Chapter 8, Lynda Delph addresses the function of floral size dimorphism in plants with unisexual flowers, but rather incompletely. The selected suite of examples from which she draws her conclusions includes species for which the breeding systems cited are not those generally applicable and for which dimorphism may not represent the situation in evolutionarily stable populations. Citations to studies on foraging behaviour by visitors to flowers of relevant species are largely missing. Nevertheless, her contribution points out that it is not always the staminate flowers that are the larger. Her synthesis, coupled with the inconclusive nature of the chapter, and of her discussion, indicates that there is much to be uncovered.

Part 3 of the book, “Model Systems”, starts with three papers on particular taxa. Scott Armbruster discusses *Dalechampia* (Euphorbiaceae) in a thorough and interesting synthesis, including phylogenetics, in which the roles of resin collecting bees are well described. Candace Galen presents her “insights” on “The Evolution of Floral Form” from her extensive research on the polymorphic species *Polemonium viscosum* (Polemoniaceae) with its differences in scent, floral size and form, and microgeographic ranges with related differences in pollinator behaviours and assemblages. Chapters 11 and 12 are about deceit pollination. Douglas Schemske and co-workers discuss the monoecious herb, *Begonia oaxaca* (Begoniaceae) in which the deceit is invoked but is over-stretched. Pollinators are attracted to and rewarded by imperfect staminate flower, but are not rewarded by imperfect pistillate flowers. The paper is interesting, but weak. Ultraviolet photography used to illustrate the visual similarity of staminate and pistillate flowers and experimental models (Figure 11.1 and 11.2) shows only artefacts which, fortunately, do not affect the authors' conclusions. In my view, deceit in pollination is better used to describe interspecific mimicry as in the next and instructive chapter by Anna-Lena Fritz and Anders Nilsson on nectarless orchids, two pollinated by bumblebees and the other by Lepidoptera. Floral and inflorescence sizes influence the relative success of male and female functions through attractiveness to pollinators. Interplant spacing may also affect reproductive success. Heterostyly, the system in which floral polymorphism is shown through consistent differences in the lengths of sporophylls, is a well known outcrossing mechanisms. Spencer Barrett, David Lloyd, and Juan Arroyo present a good introduction to the phenomenon in Chapter 13 in discussing *Narcissus* (Amaryllidaceae) in the Iberian peninsula. The chapter would have been much improved by firm editing and pruning excess verbiage in a mostly descriptive account of the interesting problems that remain to be addressed. The final chapter, and the only one by Japanese researchers, concerns pollination in *Campanula* (Campanuceae) on a 100 km string of small islands off the coast of Honshu. Their findings that flowers are smaller and increasingly likely to be self-pollinating as distance from Honshu increases accord with expectations from the few other , but uncited, studies published on pollination on islands.

All in all, this book is a compendium of papers presented at a symposium. Some are strong, some not so. The book’s title is misleading in that almost all the papers concern plant mating systems with floral biology as represented through morphology, development, attractants and rewards to pollinators, and pollinator diversity, abundance, and activity as secondary concerns. The reviewing of the contributions prior to publication was not thorough, editing is mostly adequate and more attempt should have been made to cross-reference chapters and the index made more complete. The lack of use of the translation of Sprengel’s book and of Vogel’s commentary suggests that the bicentenary was far from foremost in the minds of the symposium participants. It is noteworthy that Sprengel (1811) advocated the need for pollinators and pollination studies in crops, yet examples from economic botany are entirely missing from this volume. Although valuable for selected reference to the authors’ works, I recommend that users look well beyond this book for fuller appreciation of concepts, topics, and the literature.

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1997 ANNUAL MEETING

The **Entomological Society of Ontario** is grateful for the support received for the **Annual General Meeting** held in London on 7-8 November 1997 from: Bayer Canada; Cyanamid Crop Protection; DowElanco; Novartis Crop Protection; Rohm & Haas; United-Agri Products; and Zeneca Agro.

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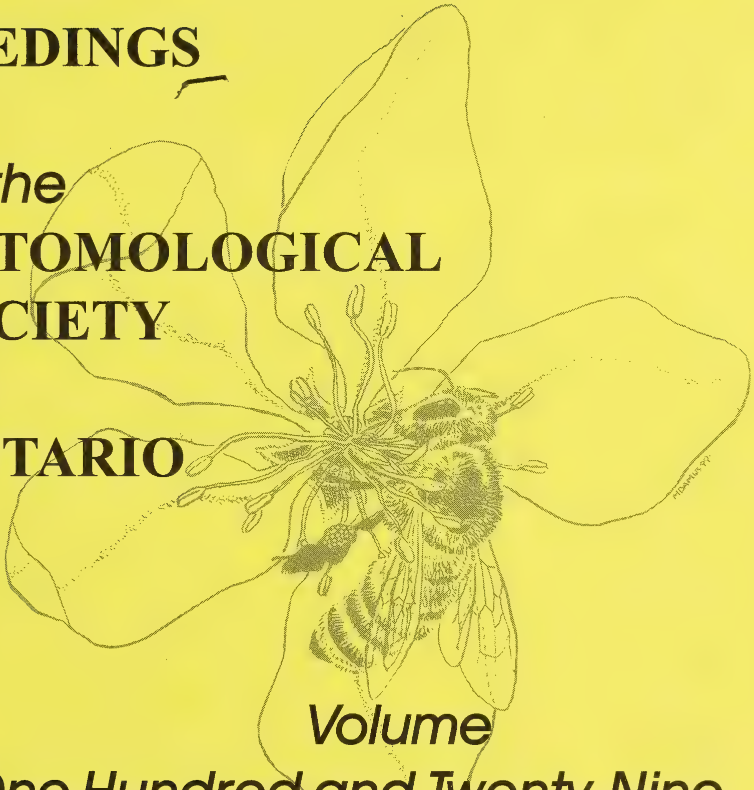

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ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume 129 ***1998***

From the Editor,

Once again, I present to the members of the ESO, and to any other readers, the latest volume of our Proceedings. This year I am particularly pleased with the contents, because the various contributions represent two highly contemporary developments in entomology. The papers that can be described as belonging to the field of applied entomology are all aimed at biological control, or the use of other non-synthetic chemical control methods. Most of the other papers are related to the current high levels of interest in bio-diversity. This volume of the Proceedings is also somewhat larger than usual, primarily because of the inclusion of an extensive paper on mayfly diversity and distribution in Canada. It is imperative that we publish structured sets of existing data on specific taxonomic groups, and on their distribution over large land-masses. Such publications will allow us to come to authoritative conclusions about loss of diversity in the future, and make it possible to link such losses to changes in local or regional environmental conditions. The biodiversity theme is also represented in a couple of other papers. The contributions on Hymenoptera in oak savannahs, and on isopods in agricultural fields focus on specific habitats rather than on large areas, a different, but equally important approach. These communications are providing us with important baseline data sets. Still other papers focus on biodiversity measurement methods or on habitat requirements of specific guilds.

Also included in this volume are a few papers that deal with more classical aspects of entomology, which I am sure will provide the reader with new facts, insight and ideas. I want to draw the readers' attention to one contribution, which falls within a somewhat controversial area of entomology — the introduction of biocontrol agents. The paper by Corrigan and co-workers on the spread of a Eurasian beetle (*Gallerucella calmariensis)*, introduced into North America for the control of a noxious Eurasian weed (purple loosestrife), was received with mixed reaction by the reviewers. I believe this mixed response is the result of our journal not having a clear policy on what constitutes an acceptable contribution.

Most of our published papers are scientific research papers based on work conducted within a rigorous methodology. Such research is usually very time consuming, and the scientific world frowns on publishing incomplete, or preliminary work. Yet, we must be aware that in matters related to ecosystem management, especially when a crisis situation is perceived, the rapid publication of new developments is often necessary. For instance, in last year's volume, a note was included on the unexpected appearance of significant infestations of European red mite in Ontario vineyards. This led to emergency funding and research in 1998. Now it looks as if this new pest problem may be included on the unexpected appearance of significant infestations of European red mite in Ontario vineyards. This led to emergency funding and research in 1998. Now it looks as if this new pest problem may be nipped in the bud. Similarly, the possible spread of *G. calmariensis* onto non-target plants is a development that may need a rapid research priority response. I therefore decided to publish these preliminary results, even though the paper does not fully conform to the normal methodological rigors. I hope that most of you will agree with this flexible policy on what should be included in our Proceedings.

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EFFECT OF FLOWERING DANDELION AS A COMPETITOR TO FLOWERS OF FRUIT TREES FOR POLLEN-COLLECTING HONEY BEES IN ONTARIO

TERENCE LAVERTY[1] and HENRY HIEMSTRA[2]

Abstract *Proc. ent. Soc. Ont.* 129: 3-8

Dandelion flowers in orchards are considered to be a serious competitor to flowering apple trees for honey bee visits. Recommendations to increase the number of bees on apple include mowing the dandelion flowers, and first introducing honey bee colonies to the orchard at the onset of apple bloom. We tested if dandelion competed with apple for pollen-collecting honey bees and if mowing the dandelion and introducing colonies increased the percentage of pollen collected from apple. The pollen collected by five resident colonies and five colonies introduced to the orchard at the start of apple bloom was sampled from 20 May – 1 June 1995. During peak apple bloom, apple pollen accounted for more than 90% of the pollen collected by both resident and introduced colonies. During the same period, only 0.1–3% of pollen collected was from dandelion even though the ratio of dandelion to apple flowers within a 3 km radius of the colonies was estimated to be 28:1. Mowing the dandelion flowers in the orchard had no effect on the percentage of pollen collected from apple or dandelion. We recommend that the common practice of mowing dandelions in apple orchards be discontinued.

Introduction

Flowering dandelion (*Taraxacum officinale*) has been considered a serious competitor to fruit bloom (e.g. Brittain 1933; Karmo and Vickery 1954; Clark 1959). Free (1968) showed that as a weed in orchards in England, dandelion competed with fruit trees for bee visits; bees became conditioned to dandelion and when the flowers closed at midday or early afternoon, relatively few bees switched to fruit blossoms. However, if colonies are first introduced to the orchard after dandelion has finished producing for the day, the chances of bees becoming conditioned to dandelion may be reduced. Free (1968) also recommended that growers eliminate dandelion in their orchards by mowing or through the use of herbicides.

Ontario fruit growers still consider dandelion to be a major competitor, with rental bees working dandelion rather that the intended apple blossoms (Anonymous 1998). As a result, much time and expense are spent on mowing the orchard floor to remove dandelion flowers. Although dandelion can produce large amounts of pollen and nectar (Szabo 1984) and Ontario beekeepers recognize dandelion as a major food source for spring build-up of overwintered colonies (Larsson et al. 1992), this does not mean necessarily that dandelion is a serious major competitor to fruit trees. In fact, casual observations by one of us (HH) suggest that the common practice of mowing flowering dandelions in orchards may be a waste of time because it removes only small numbers of a common, widespread plant that is of little interest to honey bees when fruit bloom is available.

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Our experiment was designed to test if flowering dandelion competes with fruit blossoms for visits from pollen-collecting honey bees. We also tested if mowing the dandelions and first introducing colonies to the orchard after dandelion had closed for the day had any effect on the percentage of bees collecting apple pollen.

Methods

We studied the effects of changing the flowering density of dandelion on visitation rates to blooms of fruit trees in a 3 hectare orchard at Clovermead Apiaries, Malahide Township, Elgin County, Ontario. In addition, there were 50 hectares of fruit trees available within a 3 km radius of the orchard. Of the total land area within the 3 km radius, 2400 hectares were fall ploughed (bare soil) and another 800 hectares were made up of woodlots, pasture, no-till land, residential properties, roadsides and railroad right-of-ways which supported large populations of dandelion.

On 19 May 1995, the day after the first open apple flower was recorded in the orchard, and continuing until 1 June, the end of fruit bloom, we estimated the number of dandelion flowers per hectare by counting flowering heads in 1 m^2 plots in the orchard. On 28 May, the orchard floor was mowed to assess whether or not this manipulation increased the percentage of bees collecting apple pollen relative to the percentage collecting pollen from other available plants. The number of apple flowers per hectare was estimated by counting open flowers per branch on at least ten trees of different varieties and extrapolating the daily number of open flowers per tree and per hectare over the study period.

To measure the relative amounts of different pollen types collected by colonies in the orchard, ten Ontario Agricultural College pollen traps (Smith 1973) were placed under five resident and five introduced colonies. Resident colonies had been overwintered in the orchard; introduced colonies were first moved into the orchard and placed beside the resident colonies on the evening of 21 May. At this time, dandelion flowers were closed for the day and apple was at about 10% bloom in the orchard. Morning and afternoon (AM and PM) samples of the pollen loads were collected from the trap under each colony from 20 May (resident colonies) or 22 May (introduced colonies) until 30 May 1995. Because of low pollen availability in the traps, no samples were collected on 26 May, 31 May PM, and 1 June AM. Pollen loads were kept frozen and later sorted according to colour using a colour key to the pollen of different plant species (Hodges 1952). Pollen from each plant type in each sample was weighed to the nearest 0.01 g on a Mettler PJ300 electronic balance, accurate to three decimal places. Pollen from different plants was categorized as “apple”, “dandelion” or “other”. The percentages of pollen collected during morning and afternoon collections from each plant category were transformed using the angular transformation (Sokal and Rohlf 1995) and compared separately for resident or introduced colonies using Student’s paired t-tests. Following this analysis, morning and afternoon samples from each day were pooled for each colony. The mean percentages collected per day from each plant category for resident and introduced colonies were compared over the period from 22 May – 1 June by using paired Student’s t-tests. Mean values are reported ± 1 SE.

Results

The relative abundance of apple and dandelion flowers over the study period (Table I) shows that dandelions were in peak flower at the beginning of the study (20 May) while apple was in peak flower from 23–25 May. Few dandelions were open in the orchard after 26 May because of cold weather and the flowers being mowed on May 28. During peak apple bloom, we estimated that the ratio of available dandelion heads to apple flowers within a 3 km radius of the orchard

TABLE I. Relative blooming periods of dandelion and apple flowers in the orchard during the study period 20 May – 1 June 1995.

Date	Mean number of dandelion flowers	% Apple flowers in bloom	Temperature °C*
20 May	64	2	18/24
21	65	10	21/24
22	50	50	21/28
23	39	80	20/21
24	54	80	14/14
25	29	80	15/21
26	rain, not open	50	13/7
27	not open	35	10/13
28	grass, mowed	30	16/20
29	2	25	18/32
30	2	20	23/26
31	0	15	25/15
1 June	0	2	10/13

* Temperatures recorded at 11:00 a.m. and 5:00 p.m.

was about 28:1. Other common sources of pollen at the start of the study were plum and pear, both of which were past peak flowering on 20 May, the first day that pollen was collected by the pollen traps on our colonies.

The relative mean percentages of dandelion, apple and other pollen collected did not differ between morning and afternoon samples on each day for either resident or introduced colonies (Table II), and AM and PM samples for each day were pooled in subsequent tests. Resident and introduced colonies differed in the percentages of pollen collected from available sources (22 May – 1 June); resident colonies collected more pollen from apple (87.1 ± 3.1% versus 76.8 ± 11.5%; paired $t = 4.4$, $P<0.01$) and less from dandelion (2.1 ± 0.8 versus 7.7 ± 2.3%, paired $t = 2.5$, $P<0.05$) and other sources (9.9 ± 3.0 % versus 15.4 ± 3.0%, $t = 2.25$, $P = 0.05$).

TABLE II. Mean ± SE percent pollen collected from different plant categories during morning and afternoon samples for resident (20 May – 30 May) and introduced (22 May – 30 May) colonies.

Colony type	Plant category	Mean percentage pollen collected		Paired t	P
		AM	PM		
Resident	apple	85.6 ± 5.1	85.5 ± 4.8	0.40	0.70
	dandelion	1.0 ± 0.3	1.3 ± 0.3	2.47	0.04
	other	13.4 ± 5.4	13.10 ± 5.0	0.16	0.88
Introduced	apple	80.1 ± 4.6	80.7 ± 6.3	0.34	0.74
	dandelion	7.2 ± 2.9	7.2 ± 2.8	0.26	0.8
	other	12.7 ± 3.2	12.1 ± 3.8	0.16	0.88

Both resident (Fig. 1A) and introduced (Fig. 1B) colonies collected increasingly larger percentages of apple pollen with the onset of full apple bloom (23–25 May) and continued to collect mostly (>75%) apple pollen for the duration of the study. On the day before apple reached full bloom, introduced colonies collected a greater percentage of dandelion pollen than did resident colonies (25% versus 1%), but both types of colonies collected little dandelion pollen (<5%) during the main apple bloom. Dandelion flowers were abundant in the orchard until 28 May, when the herbaceous vegetation between the trees was mowed, but small amounts of dandelion pollen were still collected after this date, indicating that colonies were harvesting dandelion pollen outside the orchard. The mean percentage of "other" pollen collected (mainly pear and plum from 20–26 May) initially accounted for about 70% of the total pollen collected by resident colonies and 25% of that collected by introduced colonies, but that declined rapidly as the apple bloom approached its peak. Other pollen sources represented between 4–20% of the total pollen collected by colonies after 27 May, and the most common pollen types during this period were hawthorn and mustard.

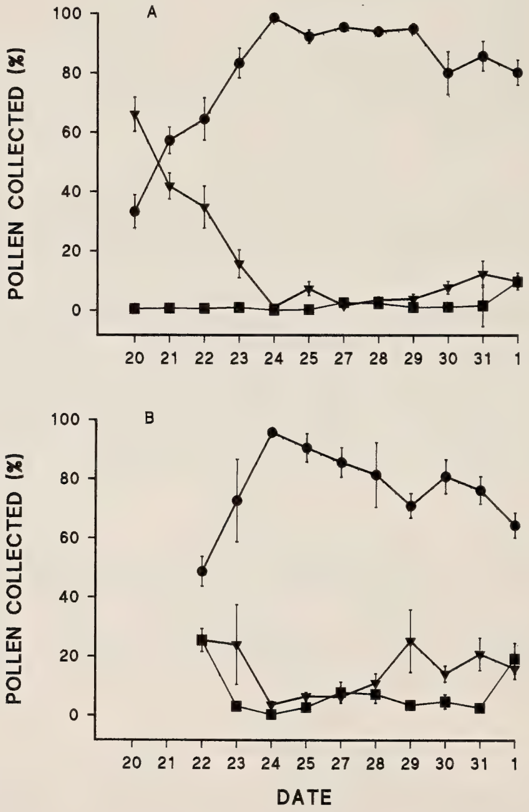

FIGURE 1. Mean percentage of pollen (by weight) collected from 20 May – 1 June, 1995 by (A) five resident honey bee colonies and (B) five colonies that were introduced into the orchard at the start of apple bloom. Symbols indicate percentage of pollen from apple (circles), dandelion (squares) and other plants (triangles); vertical lines indicate ± 1 SE.

Discussion

We monitored changes in the relative percentage of dandelion and apple pollen collected by five resident and five introduced colonies of honeybee during apple bloom in one orchard in Southern Ontario. Contrary to our expectations, colonies introduced into the orchard initially collected less apple pollen and more dandelion pollen compared to resident colonies. However, both resident and introduced colonies shifted increasingly to apple pollen which represented an average of over 80% of the pollen collected each day by colonies after apple first reached full bloom on 23 May. Even though large numbers of dandelions were flowering during peak apple bloom, dandelion accounted for only 0.1–3% of the pollen collected each day during this period (23–25 May). Thus there is no evidence that dandelion competed with apple trees for pollen foragers during our study, even though the availability of dandelion flowers far exceeded that of fruit trees within a 3 km radius of the colonies.

The methods used in this study did not allow collection of data on honey bees collecting only nectar on fruit crops or dandelion. Although the percentage of foragers collecting only nectar was less than that collecting pollen or pollen and nectar (pers. obs.), the fact remains that in our study, removal of dandelions from the orchard floor could have done little to change the availability of dandelion heads within a 3 km radius of the colonies.

In general, it is recommended that dandelions should be mowed to encourage pollinators to visit apple flowers. In our study, however, mowing of dandelions in the orchard did not increase the percentage of apple pollen collected. In fact, even after mowing in the orchard, the percentage of dandelion pollen remained at about 3–20% for the rest of the study. Our data indicate that removal of small local populations of dandelions in the orchard had no obvious effect on the percentage of colony foragers collecting dandelion pollen, and likely had no effect on dandelion nectar availability. That strongly suggests that small scale removal of dandelions in orchards during apple bloom is a waste of time and effort and that, as also concluded by Solymar (unpublished report), the elimination of dandelion from orchards is not necessary.

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A PRELIMINARY SURVEY OF SYMPHYTAN AND ACULEATE HYMENOPTERA FROM OAK SAVANNAHS IN SOUTHERN ONTARIO

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Abstract

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The sawflies and aculeate Hymenoptera collected from eight malaise traps placed in oak savannah and three in nearby non-savannah habitat for the end of August, 1994 are listed. A total of 145 species were found in the oak savannah traps. The possibility that some of the taxa discovered are oak savannah specialists is discussed. Six species sampled appear to represent first Canadian records and an additional ten species, sampled from the same sites but outside of the time frame analysed here, are also recorded as new for Canada. Two additional extralimital records are presented for prairie insects recorded East of Manitoba for the first time.

Introduction

Oak savannah has become one of the most critically threatened habitats in North America (Nuzzo 1986). While forming the required habitat of a large number of plant species (Bakowsky 1993), the more diverse insect fauna of oak savannah remains to be investigated in detail. Nonetheless, it is known that oak savannah is a prime habitat for the globally endangered Karner Blue butterfly, *Lycaeides melissa samuelis* Nabokov (Andow et al. 1994), the increasingly rare Frosted Elfin, *Incisalia irus* (Swengel 1996), and the recently investigated antennal waving wasp, *Tachysphex pechumani* Krombein (Kurczewski 1997). Consequently, the possibility that there are large numbers of additional rare species to be found in this habitat requires careful consideration. We have begun a large-scale malaise trap-based insect inventory of several oak savannah habitats in southern Ontario with the express purpose of investigating the occurrence of rare or largely restricted species to this habitat type.

Materials and Methods

Malaise traps (Sante traps Ltd., Townes style, fine mesh) were placed in five oak savannah habitats in the spring of 1994. The sites were: Karner Blue Sanctuary, Lambton County, 42°13'N 81°53'W; the Manestar Tract, 42°43'N 80°26'W; Simcoe Junction, 42°13'N 80°18'W; Nixon West, 42°13'N 80°26'W (all three in Haldimand-Norfolk County) and the Trent River Prairie 44°13'N 77°34'W. These localities were chosen based on Bakowsky (1993) and the availability of permission to trap. Two traps were operated in oak savannah at the Karner Blue Sanctuary, Manestar

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Tract and Trent River Prairie localities, one trap at Simcoe Junction and Nixon West. Traps were serviced approximately every two weeks until early September. Adjacent, non-oak savannah sites were also sampled during this period in an attempt to gauge the specificity of species collected to the oak savannah habitat. Unfortunately, only three oak savannah sites could be paired with non-oak savannah sites (Nixon West and the two Trent River Prairie trap sites); others were either on private land where access was not readily forthcoming or in areas where the traps were highly likely to have been subject to vandalism.

Because of the huge quantity of material collected, the difficulty associated with removing samples more or less simultaneously from all widely separated locations throughout the summer, and the time consuming nature of sorting malaise trap samples (Marshall et al. 1994; Danks 1996), only data from the last half of August 1994 have been analysed to date, representing the period where traps were serviced as close to simultaneously as possible. Thus, all data presented here are from 23 or 24 August until 31 August or 1 September, except at Simcoe Junction and Nixon West where the traps were operated from 26 August until 1 September.

The samples were processed to insect Order and then the Hymenoptera sorted to recognisable taxonomic units (Oliver and Beattie 1993), then the sawflies and aculeate Hymenoptera were identified to species. Unfortunately the Parasitica are both too numerous and taxonomically poorly known for exhaustive lists of species to be compiled at this time. Identifications were checked and/or corrected by A.F. for sphecids and pompilids, H.G. for sawflies, J.C. for vespids and L.P. for bees. The Formicidae were also excluded from the analysis because the mass swarming common in these highly eusocial insects would have produced highly variable results between sites depending upon the proximity of the traps to large colonies.

All specimens from this survey are currently housed at York University.

Results

Table I provides a list of the species found in each of the trap locations. A total of 635 individuals from 145 species were collected within the oak savannah habitats, far more individuals and species than were collected from the nearby control sites (90 individuals of 34 species). Results of the application of a variety of biodiversity analyses to these data will be presented elsewhere.

A total of six species were collected which seem not to have been recorded from Canada previously. These are the sawfly *Caliroa liturata* MacGillivray, the spider-wasps *Ageniella vogeli* and *Dipogon brevis brevis*, the Sphecid wasps *Psenulus pallipes* and *Mellinus bimaculatus*, and the cuckoo sweat bee *Sphecodes galerus*. Three taxa generally considered as being Carolinian fauna specialists, at least in Canada (Krombein et al. 1979), were found: *A. vogeli*, *D. brevis* and the potter wasp *Eumenes fraternus*. Although their restriction to oak savannah habitats remains uncertain, the fact that the former species was found on both sites, which are generally thought to represent higher quality oak savannahs (the Karner Blue Sanctuary and the Manestar Tract), may suggest that it is an oak savannah specialist, at least in Southern Ontario.

Discussion

As natural habitat becomes increasingly fragmented, greater emphasis must be placed on ways of determining which sites require the most urgent conservation efforts (Kirkpatrick 1983; Pressey et al. 1993). Whereas large areas may house the more popular birds and mammals, smaller sites will commonly be best assessed based upon the invertebrates found there (Kremen et al. 1993; Samways 1994; Finnamore 1996).

Oak savannah habitats are so fragmented that almost all of them are extremely small. Indeed, one of our sites consisted of a railway siding no longer than 200 metres, yet even this small piece of habitat yielded a rare specialist species, *Tachysphex pechumani*, before being destroyed in 1993 (Kurczewski 1997). Although the data presented here do not clearly document potential oak savannah specialists, a reasonable number of species previously not recorded from Canada were discovered. Furthermore, it is clear even from a simple perusal of the few identified species from the same traps, but collected outside the time frame analysed here, that there are a large number of additional interesting records from these areas. We take this opportunity to note the following first occurrences in Canada: from the Karner Blue Sanctuary between the dates of 12 August and 22 August the sawflies *Acordulocera* sp. and *Caliroa lunata*, the spider wasps *Minagenia clypeata* (Banks) and *Priocnemis hestia* (Banks), the sphecid *Passaloecus singularis* (Dahlbom), the cuckoo sweat bee *Sphecodes heraclei* Robertson and the solitary bee *Perdita albipennis palidipennis* Graenicher; from the same locality, the rare Halictine bee *Dufourea monardae* (Viereck) was collected between 4 August and 12 August 1994; from Simcoe Junction between the dates of 14 August and 26 August we found *Paracyphononyx funereus* (Lepeletier); and lastly, the rare bee *Dufourea marginata* (Cresson) was collected from the Manestar Tract in July 1994. This is a prairie species not previously recorded from Canada or East of Minnesota in the USA. Two sphecid records seem to represent easternmost extralimital localities: *Mimumesa leucopus* (Say) from Nixon West, 14–26 August, and *Podalonia mickeli* Murras from Simcoe Junction, 14–26 August, not having been recorded East of Alberta and Minnesota respectively.

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TABLE I. List of taxa recorded in the survey.

	Localities										
Taxa	1	2	3	4	5	6	7	8	9	10	11
SYMPHYTA											
PERGIDAE											
Acordulecera sp.		17		1			1	1			
TENTHREDINIDAE											
Nematus sp.					1						
Pachynematus sp.	5				1	5					3
Hoplocampus sp.							5				
Pristophora sp.							1	19			
Trichiocampus sp.								1			
Amauronematus sp.							1				
Caliroa cerasi (L.)		1									
C. lobata (MacGillivray)					4						
C. obsoleta (Norton)!		4			2	1					
C. liturata (MacGillivray)*					1						
C. petiolata Smith								1			
Metallus rohweri (MacGillivray)	1					1					
Allantus cinctus (L.)	1	1									
Ametastegia tener (Fallen)			1								
A. glabrata (Fallen)								1			
Taxonus borealis (MacGillivray)	1		1								
T. terminalis (Say)			1						1		
T. rufocinctus (Norton)			2								
T. proximus (Provancher)								2			
Aneugmenus flavipes (Norton)	1										
SIRICIDAE											
Tremex columba (L.)								1			
ACULEATA											
CHRYSIDIDAE											
Hedychridium dimidiatum (Say)					1						
Trichrysis (*Lorochrysis*) *doriae* (Gribodo)		1									
Chrysis cembricola Krombein						1	2				
C. coerulans Fab.			2	1		1	2	2			
C. derivata Buysson	1										
POMPILIDAE											
Priocnessus nebulosus (Dahlbom)		1									1
Priocnemis (*Priocnemis*) *cornica* (Say)							1				

TABLE I – continued

	Localities										
Taxa	1	2	3	4	5	6	7	8	9	10	11
P. (*P.*) *germana* (Cresson)	2										
Calicurgus hyalinatus alienatus (Smith)			2	1		1	6	2		2	3
Dipogon (*Deuteragenia*) *papago anomalus* Dreisbach	3	1			5		4	2			
D. (*D.*) *pulchripennis* (Cresson)	1	1				1	1	2	1		1
D. (*D.*) *sayi sayi* Banks	1	1			1	3	1	1			1
D. (*Dipogon*) *brevis brevis* (Cresson)**	3		1	2				1			
Auplopus architectus architectus (Say)				1		1					
A. nigrellus (Banks)	5	3									
Ageniella (*Priophanes*) *ageneoides* (Fox)	1						1				
A. (*Ageniella*) *norata* Banks	2	3						2			
A. (*A.*) *partita* Banks		1									
A. (*A.*) *vogeli* Townes *		1									
Aporus niger (Cresson)							1				
Evagetes hyacinthus (Cresson)	4	1		1							
E. ingenuus (Cresson)	2	1									
E. parvus (Cresson)	3		1								
Episyron biguttatus biguttatus (Fab.)	1	1	2					1		1	
Anoplius (*Arachnophroctonus*) *marginalis* (Banks)	1										
A. (*Pompilinus*) *insolens* (Banks)		1									
A. (*P.*) *splendens* (Dreisbach)	2										
A. (*Anoplius*) *virginiensis* (Cresson)						1	2				
Pompilus (*Ammosphex*) *angularis angularis* (Banks)	2	1				1					
P. (*A.*) *michiganensis michiganensis* (Dreisbach)	3	2	1								
P. (*Arachnospila*) *arctus* Cresson	1									1	
P. (*A.*) *scelestus* Cresson	1							2			
P. (*Anoplochares*) *apicatus* Provancher	3	2									
Minagenia congrua (Cresson)							1				

TABLE I – continued

	Localities										
Taxa	1	2	3	4	5	6	7	8	9	10	11
Ceropales maculata fraterna Smith	9	3	1			1	4	4			
VESPIDAE											
Dolichovespula arenaria (Fab.)	1					2			1		
Vespula vidua (Saussure)		1									
V. flavopilosa Jacobson					2					1	
V. maculifrons (Buysson)		2		6	3	1				4	
V. vulgaris (L.)										1	
Symmorphus canadensis (Saussure)			1	1	1					6	
Eumenes fraternus Say!			1								
Ancistrocerus catskill (Saussure)			1								
A. adiabatus (Saussure)	3		1						1	1	
Euodynerus foraminatus (Saussure)			1			1					
Parancistrocerus pennsylvanicus (Saussure)			1		2						
SPHECIDAE								4			
Podalonia violaceipennis (Lepeletier)							1				
Ammophila urnaria Dahlbom							4				
Mimesa ezra (Pate)							1				
M. huron Finnamore					2			1			
M. pauper Packard			5				1				
M. nigra (Packard)							1	1			
Psenulus pallipes parenosas (Pate)*					1						
Pemphredon lethifer (Shuckard)				1			1	1			
Passaloecus areolatus Vincent	1										
P. lineatus Vincent							1				
P. monilicornis Dahlbom					1		1			2	
Ancistromma distinctum (Smith)	3				2		1			1	
Lyroda subita (Say)				1							
Miscophus sp.						1					
Trypoxylon frigidum Smith			1	2	2	1	4	1		2	
T. figulus (L.)			1		1						
T. johnsoni Fox							1				
T. pennsylvanicum Saussure		4		1	3					1	2

TABLE I – continued

	Localities										
Taxa	1	2	3	4	5	6	7	8	9	10	11
T. backi Sandhouse	5	3		5	1		1			2	1
Rhopalum clavipes (L.)					1					1	
R. coarctatum (Scopoli)					4		3			3	
Crossocerus elongatus elongatus Vander Linden	1										
C. lentus (Fox)					1						
C. maculiclypeus (Fox)	1	1									
C. annulipes annulipes (Lepeletier and Brulle)		2			2			3		4	
C. harringtoni (Fox)								2			
C. impressifrons (Smith)		1								2	
C. maculipennis (Smith)					1						
Crabro advena Smith					1						
Ectemnius lapidarius (Panzer)			1							1	
E. cephalotes (Olivier)				5	3		4	3	1	2	
E. continuus (Fab.)					1			1			
E. dives (Lepeletier and Brulle)								1		1	
E. borealis Finnamore			1				1				
Lestica producticollis (Packard)	1										
Mellinus bimaculatus Packard*	1						2	10	1		
Alysson guignardi Provancher				1							
Philanthus politus Say		1									
Cerceris atramontensis Banks							1				
COLLETIDAE											
Colletes simulans armatus Patton	1							1			
Hylaeus illinoensis Robertson			1								
H. modestus Say									1		
ANDRENIDAE											
Andrena hirticincta Provancher			2				1	2			
Pseudopanurgus sp.				1						1	
HALICTIDAE											
Augochlora pura Say			11				2	1		1	
Augochlorella striata (Provancher)	12	4	6	5	1		5	4		5	

TABLE I – continued

	Localities										
Taxa	1	2	3	4	5	6	7	8	9	10	11
Augochloropsis metallica (Fab.)	1									2	
Agapostemon radiatus (Say)	2	1	6	6			5	8		2	
A. splendens (Lepeletier)							1				
A. virescens (Fab.)					1					1	
Halictus (*Halictus*) *ligatus* Say					1						
H. (*H.*) *rubicundus* Christ								1			
H. (*Seladonia*) *confusus* Smith	1			1			5	1			
Lasioglossum (*Lasioglossum*) *acuminatum* McGinley	6	1									
L. (*L.*) *coriaceum* (Smith)	3				1	1	14	3			
L. (*L.*) *fuscipenne* (Smith)							1				
L. (*L.*) *leucozonium* (Schrank)	1										
L. (*L.*) *zonulum* (Smith)	1		2								
L. (*Evylaeus*) *divergens* Lovell			1					1		1	
L. (*E.*) *pectoralis* Smith	7				1		1				
L. (*Dialictus*) *admirandus* (Sandhouse)	1										
L. (*D.*) *cressonii* Robertson			1							9	
L. (*D.*) *laevissimum* (Smith)	1		1							1	
L. (*D.*) *lineatulus* Crawford	2		2		1					1	
L. (*D.*) *nigro-viridis* (Graenicher)										1	
L. (*D.*) *nymphaearum* Robertson		1	1							1	
L. (*D.*) *perpunctatus* Ellis		2	1								
L. (*D.*) *pilosus* Smith	3	6	3								
L. (*D.*) *versans* Lovell			1		1						
L. (*D.*) *vierecki* (Crawford)							1	3			
L. (*D.*) *viridatus* Lovell			1								
Sphecodes clematidis Roberston	3										
S. galerus Lovell and Cockerell*					1						
S. persimilis Lovell and Cockerell			4	1	1						
S. solonis Graenicher	2				1						
MEGACHILIDAE											
Megachile. sp.							1	2			

TABLE I – continued

	Localities										
Taxa	1	2	3	4	5	6	7	8	9	10	11
APIDAE											
Anthophora terminalis Cresson				1							
Ceratina calcarata Robertson	4		1	5	14		1	2		6	
C. metallica Smith	1										
Totals	129	78	75	50	75	25	101	102	7	71	12
Grand Total											725

* Species recorded for Canada for the first time.
! Carolinian specialists.
The numbered localities are as follows:
1. Karner Blue sanctuary, trap 1.
2. Karner Blue sanctuary, trap 2.
3. Nixon West.
4. Simcoe Junction.
5. Trent River Prairie, trap 1.
6. Trent River Prairie, trap 2.
7. Manestar tract, trap 1.
8. Manestar tract, trap 2.
9. Nixon West non-oak savannah area.
10. Trent river Prairie non-oak savannah trap 1.
11. Trent River Prairie non-oak savannah trap 2.

PHENOLOGY AND HABITAT PREFERENCES OF THREE SPECIES OF GROUND BEETLES (COLEOPTERA: CARABIDAE) ASSOCIATED WITH ALVAR HABITATS IN SOUTHERN ONTARIO

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Abstract

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The phenology and habitat preferences of three little known and rarely collected species of ground beetles (Coleoptera: Carabidae) were studied in alvars (limestone plains with sparse, xeric-adapted vegetation) in southern and eastern Ontario in 1996–1997. *Agonum nutans* (Say) is an autumn breeder, with overwintering larvae and adults, and a peak of adult activity in late summer. *A. nutans* was collected only in alvar grasslands and appears to prefer open habitats with dense grassy vegetation and small bodies of standing water. *Chlaenius purpuricollis purpuricollis* Randall is a spring breeder, with overwintering adults and a peak of adult activity in late spring and early summer. This species was collected in three alvar types: alvar pavement, alvar savanna grassland, and alvar grassland and appears to prefer open, dry habitats with grasses or sparse herbaceous vegetation. The distribution of *C. p. purpuricollis* is highly localized within its known range. *Pterostichus novus* Straneo is an autumn breeder, with peak adult activity in late summer. This species was collected in all alvar sites sampled and is one of the most abundant ground beetles in Ontario alvars. In the study area, it appears to prefer open dry habitats with bare rock and sparse vegetation, or native grassland habitats. All three species are abundant in Ontario's alvars and are rarely collected in other habitats in this region; they appear to be strongly associated with alvars in southern Ontario. Additional morphological characters, specifically the carina and the sculpturing of the posterolateral impression of the pronotum, are provided to distinguish *P. novus* from the similar species, *P. coracinus* Newman.

Introduction

Alvars are primarily open areas with a substrate of bare limestone overlaid by sparse vegetation (Catling and Brownell 1995). They are highly restricted in their global distribution (the Baltic and Great Lakes regions) and existing alvars are small both in area and number. Alvars are also under great pressure from natural and anthropogenic stresses such as fire, livestock overgrazing, quarrying, urban development and invasion by introduced species that threaten populations of the native alvar biota. The community of organisms that lives in alvars is adapted to the extremes of temperature and humidity that are characteristic of this habitat (see Catling and Brownell (1995) for a review of alvars). For these reasons, there is increasing interest in the biological diversity of alvars for conservation purposes.

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TABLE I. Location of sample sizes and alvar types in 1996–1997.

Site	Location	Alvar type	Year sampled
1	Misery Bay Prov. Park, Manitoulin Is. (45°47′26″N; 82°45′00″W)	alvar pavement	1996
2	10 km W Evansville, Manitoulin Is. (45°49′18″N; 82°41′04″W)	alvar shrubland	1996
3	10 km SW Gore Bay, Manitoulin Is. (45°52′12″N; 82°31′48″W)	alvar savanna grassland	1996
4	10 km W Gore Bay, Manitoulin Is. (45°53′45″N; 82°34′41″W)	alvar grassland	1996
5	5 km E Camden East (44°20′19″N; 76°47′49″W)	alvar grassland	1997
6	3 km N Miller Lake, Bruce Peninsula (45°07′46″N; 81°26′44″W)	alvar pavement	1997
7	Cabot Head, Bruce Peninsula (45°14′44″N; 81°18′28″W)	alvar grassland	1997
8	1.5 km NE Dalrymple (44°41′02″N; 79°05′31″W)	alvar grassland	1997
9	7.5 km E Seabright (44°38′27″N; 79°03′59″W)	alvar shrubland	1997
10	5 km N Almonte (45°16′14″N; 76°10′58″W)	alvar grassland	1997

In the course of an inventory of selected insect taxa in the alvars of southern Ontario, we collected several hundred specimens of three species of ground beetles (Coleoptera: Carabidae) that are rarely collected in Ontario and are uncommonly collected throughout their known range. These species are *Agonum nutans* (Say), *Chlaenius purpuricollis purpuricollis* Randall and *Pterostichus novus* Straneo. Little is known of their phenology or habitat preferences and our collections have provided the opportunity to study these aspects of their biology. The purpose of our paper is to describe the phenology and habitat preferences of these three species in southern Ontario alvars. We also discuss additional morphological characters that allow reliable differentiation of *Pterostichus novus* from the similar, sympatric species, *Pterostichus coracinus* Newman.

Materials and Methods

Four alvar types, in ten localities in southern and eastern Ontario, were sampled (Table I). The alvar pavements (Sites 1, 6) were mostly bare or moss/lichen-covered flat limestone with sparse grasses and shrubs growing in cracks. Some jack pines (*Pinus banksiana* Lamb.; Pinaceae) and eastern white cedars (*Thuja occidentalis* L.; Cupressaceae) were interspersed through the sites. The alvar shrublands (Sites 2, 9) were approximately 65% covered by shrubs such as common juniper (*Juniper communis* L.; Cupressaceae); the rest was almost entirely open limestone. There were some narrow, deep cracks in the bedrock (ca. 10 cm wide and 1.5–2.0 m deep), with some eastern white cedars and white pines (*Pinus strobus* L.; Pinaceae) in the wider cracks where soil has accumulated. The alvar savanna grassland (Site 3) had a thicker soil layer, up to 25 cm deep, but a few bare rock openings remained. There was approximately 65% coverage by grasses and sedges, with some bur-oak trees (*Quercus macrocarpa* Michx.; Fagaceae). The alvar grasslands (Sites 4, 5, 7, 8, 10) had a soil layer up to 25 cm deep and were approximately 95% covered by grasses and other herbaceous vegetation, with few trees. All the alvar grasslands had standing water in temporary pools until early June; most became dry after that date although the topography of the alvar grassland on Manitoulin Island (Site 4) enabled temporary pools to persist during most of the sampling period in 1996.

Beetles were collected using white cup pitfall traps, yellow pan traps, flight intercept traps and hand collecting. Propylene glycol or ethylene glycol was used as a preservative, with Kodak Photoflo® or liquid detergent used as a wetting agent. Specimens were removed from traps at biweekly intervals in 1996 and 1997 from mid-May until mid-September.

Specimens collected in the study were deposited in the Lyman Entomological Museum, McGill University, Ste-Anne-de-Bellevue, Quebec (LEM), or the Canadian National Collection of Insects, Ottawa, Ontario (CNC). Approximately 200 additional specimens of *P. novus* and numerous specimens of *P. coracinus* from the CNC, the Carnegie Museum of Natural History, Pittsburgh, PA (CMNH) and the National Museum of Natural History, Smithsonian Institution, Washington, DC (USNM), were examined to determine the degree of morphological variation in the species in other parts of their range.

Results

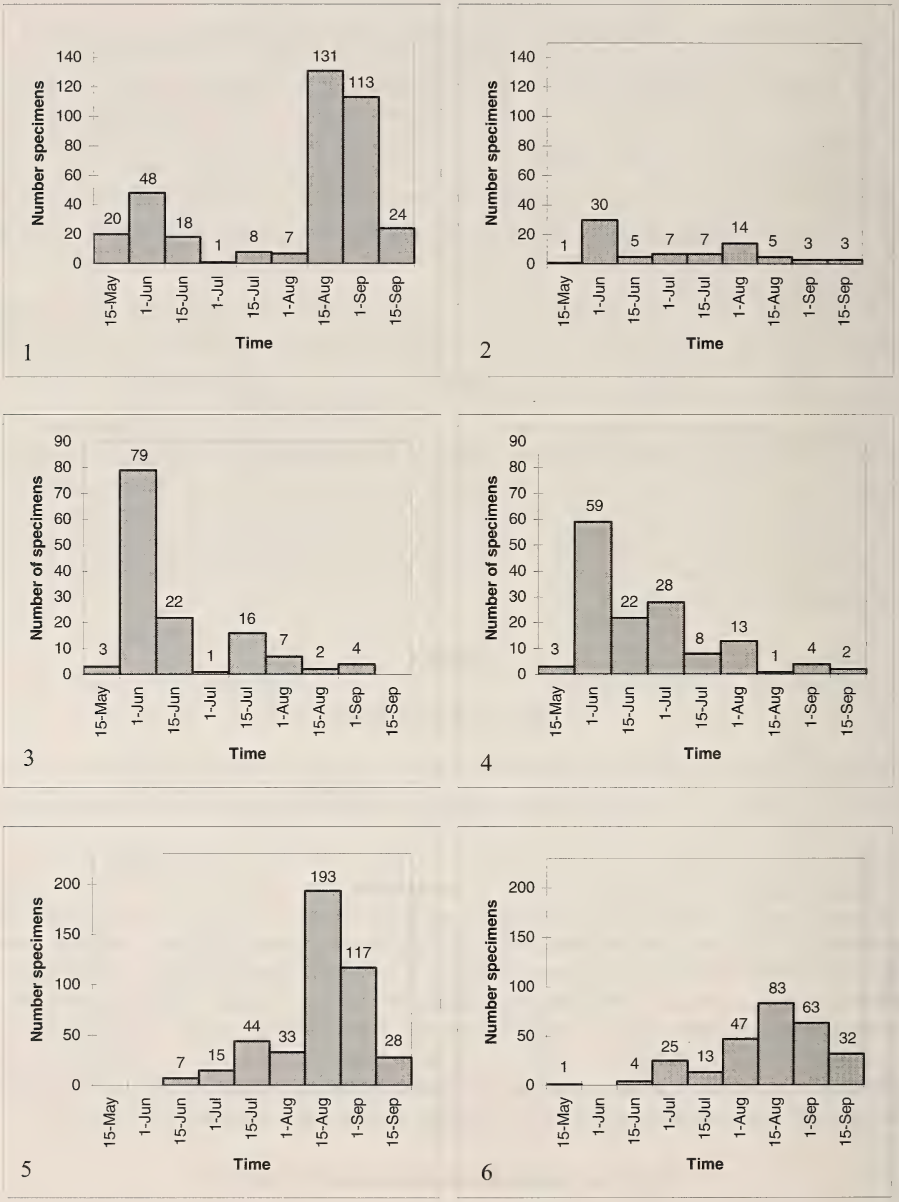
Agonum nutans (Say)

Phenology. Specimens were collected from mid-May until mid-September in both 1996 and 1997 (Figs. 1–2). In 1996, 370 specimens were collected with a bimodal peak of abundance. The first peak was in early June (48 specimens) and the second was in mid-August (131 specimens) to early September (113 specimens) (Fig. 1). Seventy-one teneral specimens were collected in 1996 from mid-July (1 specimen) until mid-September (6 specimens); the peak abundance of teneral specimens was in mid-August (37 specimens) and early September (27 specimens). The pattern of abundance in 1997 was quite different. A total of 75 specimens was collected, with the greatest peak of abundance in early June (30 specimens) (Fig. 2). The late summer peak seen in 1996 was virtually absent in 1997; 14 specimens were collected in early August (Fig. 2). Only 4 teneral specimens were collected in 1997: 2 in early July, and 1 each in early August and mid-September.

Habitat. We collected *A. nutans* exclusively in alvar grasslands (Sites 4, 5, 7, 8, 10), with the great majority (370 of 445 specimens, 83.1%) taken in Site 4 in 1996 (Table II).

Chlaenius purpuricollis purpuricollis Randall

Phenology. Specimens were collected from mid-May until early September in 1996 and from mid-May until mid-September in 1997 (Figs. 3–4). In 1996, 134 specimens were collected with a single peak of abundance in early June (79 specimens) (Fig. 3). Four teneral specimens were collected in 1996, 2 in early August and 2 in early September. In 1997, 140 specimens were



FIGURES 1–6. Phenology of selected ground beetles in Ontario alvars. 1. *Agonum nutans* (1996); 2. *A. nutans* (1997); 3. *Chlaenius purpuricollis purpuricollis* (1996); 4. *C. p. purpuricollis* 1997); 5. *Pterostichus novus* (1996); 6. *P. novus* (1997).

TABLE II. Abundance of selected ground beetles in alvar sites in 1996–1997. Site numbers correspond to those in Table I.

Species	Specimens collected per site										Total
	1	2	3	4	5	6	7	8	9	10	
Agonum nutans				370	45		2	2		26	445
Chlaenius purpuricollis purpuricollis	13		115	6	8			7		125	274
Pterostichus novus	294	33	108	2	22	86	35	16	2	107	705

collected, with a peak of abundance in early June (59 specimens) (Fig. 4). Three teneral specimens were collected in 1997: 1 each in mid-July, mid-August and early September.

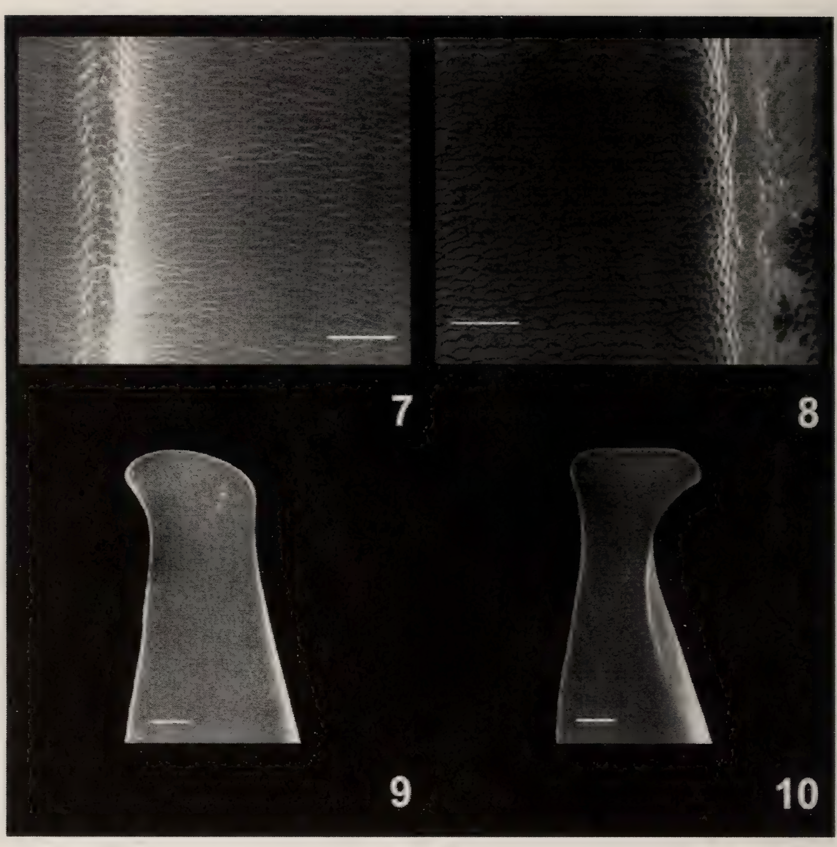
Habitat. We collected *C. p. purpuricollis* in three alvar types: alvar grasslands (146 specimens total from sites 4, 5, 8, 10); alvar savanna grassland (115 specimens from site 3); and alvar pavement (13 specimens from site 1) (Table II).

Pterostichus novus Straneo

Phenology. Specimens were collected from mid-June until mid-September in 1996 and from mid-May until mid-September in 1997, although in 1997 only a single specimen was collected prior to mid-June (Figs. 5-6). In 1996, 437 specimens were collected with a single peak of abundance in mid-August (193 specimens) (Fig. 5). Thirty-one teneral specimens were collected in 1996, between early July (2 specimens) and early September (3 specimens); most teneral specimens (18) were collected in mid-August. In 1997, 268 specimens were collected, with the peak of abundance in mid-August (83 specimens) (Fig. 6). Twelve teneral specimens were collected in 1997, from early July (2 specimens) until mid-August (5 specimens).

Habitat. *Pterostichus novus* was collected in all ten alvar sites. It was most abundant in the alvar pavement at Site 1, with 294 specimens collected (41.7% of the total) (Table II). Other sites where the species was abundant included the alvar savanna grassland at Site 3, the alvar pavement at Site 6 and the alvar grassland at Site 10; these four sites accounted for 84.4% of the specimens of *P. novus* collected (Table II). *Pterostichus novus* and *Poecilus l. lucublandus* (Say) were the only carabid species collected in all ten sites, and *P. novus* was the third most abundant ground beetle species of the 143 species collected in this study (only *P. l. lucublandus* and *Harpalus faunus* Say were more abundant).

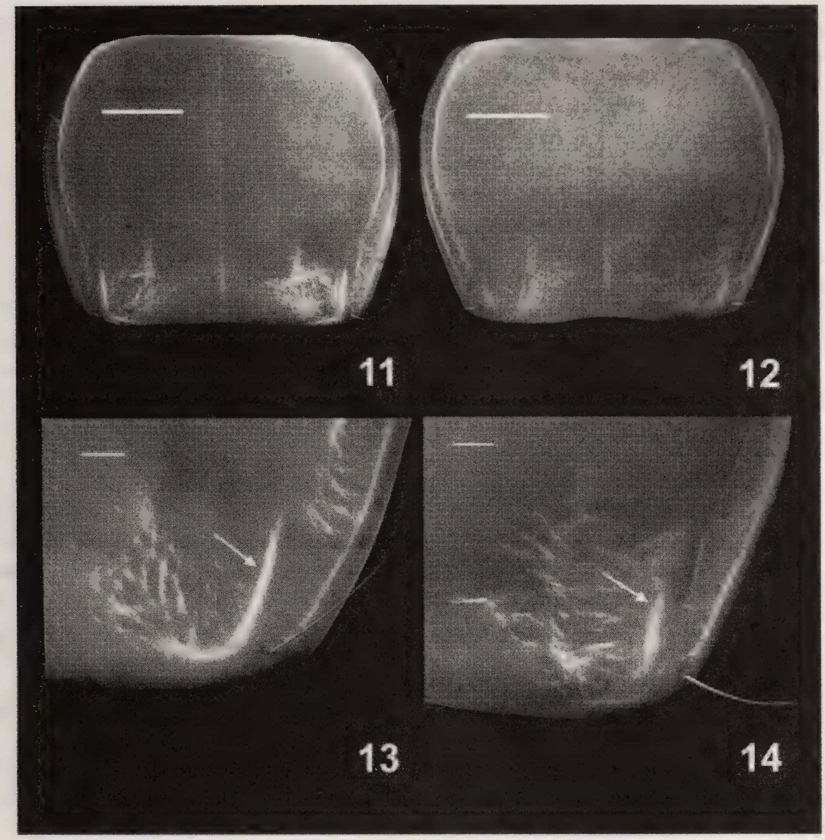
Recognition of *P. novus* and *P. coracinus*. Adults of *P. novus* are very similar to those of *P. coracinus*, which was another abundant species in our alvar sites. Lindroth (1966) considered the two species closely related, although there is no phylogenetic support for this interpretation. In his key to species, Lindroth separated the two species on the presence of a minute tubercle inside the shoulder of the elytra, the development of microsculpture on the frons and pronotum and the development of a ridge on the first metatarsus. All of these characters are either difficult to see or variable in one or both of the species. Lindroth discussed two additional distinguishing characters under his treatment of the two species — the shape of the elytral microsculpture and the shape of



FIGURES 7–10. 7–8. Microsculpture on elytral interval 3 near middle: 7. *Pterostichus novus*; 8. *Pterostichus coracinus*. 9–10. Apex of median lobe in ventral view: 9. *P. novus*; 10. *P. coracinus*. Scale bars: Figures 7–8 = 50 μm; figures 9–10 = 100 μm.

the apex of the median lobe in males. With large series of both species available for examination, we were able to confirm the reliability of these two characters, as well as identifying additional characters that distinguish both sexes of the two species.

In *P. novus* the elytral microsculpture on the discal intervals has very transverse sculpticells, with or without a few isodiametric sculpticells near the middle (Fig. 7). In *P. coracinus* the elytral microsculpture usually consists of isodiametric sculpticells, with a few transverse sculpticells (Fig. 8); in a few specimens most sculpticells are slightly transverse (2–3 times longer than wide). Unfortunately, recognition of this character requires a binocular microscope with high magnification (> 80 times) and a strong light source with an efficient light diffuser near the specimen. The apex of the median lobe in males of *P. novus* has a broadly rounded lobe on the left side (Fig. 9), whereas the apex of the median lobe in males of *P. coracinus* has an acute lobe on the right side (Fig. 10). The apex of the median lobe is slightly extruded in about 90% of mounted male specimens, which almost eliminates the need for dissection.



FIGURES 11–14. 11–12. Pronotum (dorsal view): 11. *Pterostichus novus*; 12. *Pterostichus coracinus*. 13–14. Right posterolateral angle of pronotum: 13. *P. novus*; 14. *P. coracinus*. Arrows point to medial margin of carina. Scale bars: Figures 11–12 = 1 mm; figures 13–14 = 200 μm.

The most reliable and easily visible character that we found to separate the species was one not mentioned by Lindroth (1966). In *P. novus,* the posterolateral impression of the pronotum has a carina sharply outlined on the inner side (Figs. 11, 13); medial to the carina the posterolateral impression has irregular, indistinct punctures (rarely with a few irregular striations) (Figs. 11, 13). In *P. coracinus*, the posterolateral impression of the pronotum has the inner side of the carina not clearly defined (Figs. 12, 14) and medial to the carina the posterolateral impression has irregular striations (rarely with a few indistinct punctures) (Figs. 12, 14).

In addition to the specimens collected in this study, we examined 205 specimens of *P. novus* from the CMNH, CNC and USNM from three provinces (MB, ON, QC) and eight states (KS, MI, MN, ND, NY, OH, PA, SD). Specimens from most localities in Ontario and Michigan were similar to the specimens collected in our study, but those from the other regions showed variation in several morphological characters. These differences may be even more pronounced in populations elsewhere in the range of the two species. For this reason, we suspect that the distinguishing characters discussed here may be reliable for separating *P. novus* and *P. coracinus* only in the Great Lakes region.

Discussion

Phenology. Generally, the annual cycles of north-temperate ground beetles are divided into two broad patterns: "spring breeders" and "autumn breeders" (Larsson 1939; Thiele 1977). Spring breeders are characterized by overwintering adults, spring and early summer reproduction and uninterrupted larval development through the summer to produce the next generation of adults by late summer. Spring breeders may be recognized by a peak of adult activity in late spring and early summer and the presence of teneral adults late in the summer. Autumn breeders are usually characterized by overwintering larvae undergoing diapause and, usually, overwintering adults, completion of larval development the following spring and summer, and emergence of adults and reproduction later in the summer. In autumn breeders, the peak of adult activity and of teneral adults occurs in late summer and there is often another peak of adult activity early in the season as overwintering adults emerge from hibernation.

Agonum nutans appears to be an autumn breeder. The 1996 data showed a peak of abundance of adults in mid-August and the presence of teneral adults from mid-July until mid-September. There was an additional peak of adult activity in early summer, probably due to the emergence from hibernation of overwintering adults (Fig. 1). Blatchley (1910) reported adult hibernation of *A. nutans* in Indiana; our 1996 results were consistent with Blatchley's observations. Our 1997 data did not show the same trend; the peak of abundance in early June was present as expected, but the second peak of adult abundance in late summer was much smaller than in 1996, as was the total number of specimens collected (Fig. 2). We suspect that extrinsic factors (e.g., a marked dry period in July) may have disrupted the population in 1997, resulting in the reduction of adult emergence in late summer and the apparent absence of the late summer peak of activity. Additional study of this species in alvar sites in subsequent years might resolve this anomaly.

Chlaenius purpuricollis purpuricollis is a spring breeder. Adult abundance peaked in early June in both 1996 and 1997 as overwintering adults emerged from hibernation. The few teneral adults collected were taken between mid-July and early September, indicating that the next generation of adults had emerged from pupation (Figs. 3–4). Lindroth (1969) suggested that adult hibernation occurs in all species of *Chlaenius* occurring in Canada and the phenology of *C. p. purpuricollis* is consistent with that hypothesis.

Pterostichus novus is an autumn breeder. Both adult abundance and the number of teneral adults peaked in mid-August in both sampling years (Figs. 5–6). There was no appreciable peak of adult activity early in the season, suggesting that adults may not overwinter, or that they do so in relatively low numbers. The phenology of *P. novus* collected in this study corresponded closely to patterns in other northeastern North American *Pterostichus* species characterized as autumn breeders (Barlow 1970; Bousquet 1986). Epstein and Kulman (1990) collected over 600 specimens of *P. novus* in Minnesota and found a slightly different seasonal pattern. They inferred that the species overwintered as larvae, as we did, but the peak of adult activity was from late June to late July, with teneral specimens collected in early to mid-June, earlier than in our sites.

Habitat preferences. We collected *A. nutans* only in alvar grasslands. Based on our data it appears that the species is strongly associated with open areas with dense grassy vegetation, at least in southern Ontario; standing bodies of water may be required, as the site from which the great majority of specimens was collected (Site 4) had a number of persistent temporary ponds, and the alvar grasslands in general were wetter than the other sites as the season progressed. Most species of *Agonum* are associated with the margins of standing water, although a few species are associated with forests or dry, open habitats (Lindroth 1966). There is little published information on the natural history of *A. nutans*. Lindroth (1966) reported that most of the Canadian specimens that he examined were taken in drift along the shoreline of Lake Erie. Will et al. (1995) reported a specimen of *A. nutans* in the Ohio State University Collection from the shore of Lake Erie in Michigan and there is an unpublished record of *A. nutans* from lakeplain prairie in the upper peninsula of Michigan (D. Cuthrell, personal communication). Adults are fully winged (Lindroth 1966) and therefore may be capable of dispersing between sites. *Agonum nutans* is widespread in eastern North America, with published records from 25 states in the east and midwest and two provinces (ON, QC) (Bousquet and Larochelle 1993) and it is difficult to speculate on preferred habitats in regions other than those in the study area.

Chlaenius purpuricollis purpuricollis was collected in alvar savanna grassland, alvar grassland and alvar pavement, although most specimens were taken in the first two alvar types (Table II). The distribution of this species was localized within the alvar sites sampled; 240 specimens (87.6% of the total) were collected in two sites (sites 3 and 10, Table II). Like *A. nutans*, this species apparently prefers open habitats with relatively dense vegetation (as in the alvar savanna grassland and alvar grasslands). Although standing water was a feature of the alvar grasslands, this was not the case with the other alvar types. Thus, the requirement for proximity to water bodies is unknown in this species. Lindroth (1969) considered almost all Canadian species of *Chlaenius* hygrophilous, although he noted that the ecology of *C. purpuricollis* was unknown. Blatchley (1910) reported *C. purpuricollis* as a rare species occurring along the shores of Lake Michigan. *Chlaenius purpuricollis purpuricollis* is widespread in North America with published records from 15 states in the southwestern (CO, NM, UT), mid-western (IA, IL, IN, KS, NE) and eastern (CT, MA, NH, NJ, NY, PA, RI) United States and three Canadian provinces (MB, ON, QC) (Bousquet and Larochelle 1993), although its distribution within this range is highly localized (Lindroth 1969).

Pterostichus novus appears to be associated with all types of alvars, but was most abundant in the open and dry habitats of the alvar pavements and alvar savanna grassland (Table II). Based on our results, it appears that *P. novus* is most abundant in such open, xeric habitats. Although this may be a valid assumption in southern Ontario, it is by no means consistent across the geographical range of this species. Lindroth (1966) reported collecting four specimens of *P. novus* in a "moist hardwood forest among dead leaves near a small brook" at Aweme, Manitoba. Snider and Snider (1986) collected *P. novus* in deciduous forests in the upper peninsula of Michigan and Epstein and Kulman (1990) collected over 650 specimens of *P. novus* in a variety of habitats in Minnesota, including mesic cottonwood forests, drier upland oak forests, and mesic old field habitats. In contrast to our results, *P. novus* was least abundant in the field site in Epstein and Kulman's study, and they collected no specimens in xeric habitats. Bousquet and Larochelle (1993) recorded *P. novus* from seven states and two provinces in east-central North America (MB, MI, MN, ND, OH, ON, PA, SD, WI). In addition, one of us (H.G.) collected 15 specimens of *P. novus* in an alvar at St. Julius, Quebec in 1997. Despite intensive sampling in leaf litter of moist and mesic forests in Ontario and Quebec in recent years, we are aware of no specimens of *P. novus* collected in the area.

Alvar associations in ground beetles. Although *A. nutans* is rarely collected outside alvars in Ontario, this is not the case elsewhere in its range. Blatchley (1910) reported that the species was collected frequently in northern Indiana. Both Blatchley (1910) and Lindroth (1969) considered *C. purpuricollis* rare and Lindroth noted that, although almost transcontinental, it is a localized species within its known distribution. *Pterostichus novus* is rarely collected in Ontario outside alvar habitats. With our collections from several alvars in southern and eastern Ontario, and Quebec, and a large series of specimens from an alvar in Michigan, we consider *P. novus* a characteristic ground beetle of alvar ecosystems in southern Ontario. However, the habitat preferences of *P. novus* in other parts of its range are quite different and there is little evidence supporting a close association of *P. novus* with grassland habitats in areas other than Ontario, Quebec and parts of Michigan. The differences in habitat preferences and phenology, and the great morphological variation of *P. novus* across its geographic range suggests that this species may be a complex in need of more detailed taxonomic study.

Their status and abundance elsewhere in their range notwithstanding, these three species are rarely collected in Ontario and appear to be quite abundant in alvars. In fact, they were among the numerically dominant species of ground beetles in our sample sites. Because of their abundance, we consider *A. nutans*, *C. p. purpuricollis* and *P. novus* strongly associated with alvars in Ontario. Their abundance in these habitats and their apparent rarity elsewhere in Ontario provide support in addition to plant distribution (Catling and Brownell 1995) for the recognition of the unique nature of alvar ecosystems.

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THE EFFECT OF DIFFERENT PRESERVING FLUIDS ON INSECT CATCHES IN YELLOW PAN TRAPS

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Abstract

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The effect of three commonly used preserving fluids (ethylene glycol, propylene glycol, salt water) on the numbers of insects collected in yellow pan traps was examined. Statistically significant differences were found between overall numbers of Coleoptera, Diptera, Homoptera and Hymenoptera collected in traps using different fluids. Salt water traps collected the highest numbers of Diptera and Homoptera and the most insects overall. Salt water was second to ethylene glycol in total numbers of Hymenoptera, but the difference was not significant. Propylene glycol traps collected the lowest numbers of Diptera, Homoptera and Hymenoptera. Coleoptera were most abundant in propylene glycol traps, followed by ethylene glycol and salt water. Differences were also found between overall numbers of selected families within the above higher taxa, although the relative abundance of individual families in the three fluids did not necessarily correspond to that at the ordinal level. The reasons for the differences are not clear but colour and odour of the fluids may play a role. Although quantitative differences were documented, other considerations such as rate of evaporation, preservative action and toxicity of the preserving fluids may play a role in determining which fluid is most suitable in a particular sampling program.

Introduction

Pan traps are used extensively for the collection of insects in systematic and ecological studies across a wide range of habitats. The attractiveness of pan traps in monitoring or inventory studies lies in the fact that the number of insects caught depends primarily upon the size of the population and the activity patterns of the insects. However, several other factors influence the size of the catch, including temperature and moisture levels (Spence and Niemalä 1994), surrounding vegetation (Greenslade 1964), number, size, shape and arrangement of traps (Spence and Niemalä 1994), material used to make the traps (Luff 1975), trap colour (Kirk 1984) and the type of preserving fluid used in the traps (Luff 1968; Greenslade and Greenslade 1971).

Preserving fluids are added to pan traps to prevent escape and predation by live insects and to prevent decomposition of dead specimens in traps that are left unattended for a period of time (Marshall et al. 1994). Soon after the use of preserving fluids for these purposes became widespread, there was increasing evidence, largely anecdotal, that particular insect taxa are attracted or repelled by certain preserving fluids. There has been little quantitative research on this topic; Luff (1968) examined the effects of formalin on Coleoptera collected in pitfall traps and Greenslade and Greenslade (1971) compared methylated spirit (an ethanol-methanol mixture), an alcohol-mixture and water. Both studies concluded that insects were differentially attracted to the fluids, although the effect varied between taxa. There has been little quantitative effort to compare the attractiveness or repellence of preserving fluids more commonly used in current studies. The objective of this study was to compare the numbers of insects across a range of orders and families collected in pan traps filled with three commonly used preserving fluids: ethylene glycol, propylene glycol and salt water.

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Materials and Methods

The study was conducted in June and July 1996 at the Morgan Arboretum, McGill University, Ste-Anne-de-Bellevue, Quebec. The study area was a heterogeneous, old field habitat dominated by several genera of grasses. At the time of the study the grass surrounding the traps was approximately 30 cm in height and sparse enough so that traps were not obstructed by overhanging vegetation and were readily visible from above.

Pan traps were Spectrum Yellow (Smithe 1975), plastic 355 ml bowls, 15 cm in diameter and 4 cm deep (Solo Cup Co., Urbana, IL, USA). Traps were set with the upper rim flush with the soil surface (Marshall et al. 1994). To prevent disturbance of the traps by mammals, each trap was covered with a square grid of poultry netting staked to the ground at each corner. Three preserving fluids were used in the pan traps: propylene glycol (purchased as recreational vehicle plumbing antifreeze, Canadian Tire® brand); ethylene glycol (purchased as automobile radiator antifreeze, Canadian Tire® brand) diluted with an equal volume of water; and a saturated solution of salt water. A drop of Kodak Photoflo® was added to each trap to break the surface tension of the preserving fluid.

A Randomized Block Design was used with three replicates of each preserving fluid per block (nine traps per block), and three blocks, for a total of 27 traps. Within each block traps were arranged in a 3 × 3 grid at 1.5 m intervals, with approximately 5m between each block. Traps were operated for four sampling periods of five days each. After each sampling period all insects were removed, rinsed in water and preserved in 70% ethanol. Traps were rinsed, reset, and refilled with preserving fluid. The distribution of preserving fluids between traps was randomized at each sampling interval.

The number of specimens of selected taxa collected in each of the three fluids was compared. At least 15 orders of insects and other arthropods were collected, but orders other than Coleoptera, Diptera, Homoptera and Hymenoptera comprised less than 2% of the total abundance and were excluded from the analysis. Within each order, selected families or superfamilies were chosen for analysis because they are commonly collected in yellow pan traps, they were abundant in our samples and they are frequently used as study taxa in other sampling programs or biodiversity studies. These taxa included Carabidae and Staphylinidae (Coleoptera); Mycetophilidae, Dolichopodidae, Phoridae, Sphaeroceridae and Chloropidae (Diptera); Cicadellidae (Homoptera); and Apoidea, Chalcidoidea, Proctotrupoidea, Ichneumonidae and Braconidae (Hymenoptera). An F-test, Type III SS test and contrasts, calculated following a General Linear Models (GLM) procedure (SAS Institute 1989) and a Duncan's Multiple Range Test (Zar 1984) were used for comparison of specimen numbers within and between treatments.

Results

A total of 18365 specimens in the orders Coleoptera, Diptera, Homoptera and Hymenoptera was collected (Table I). Homoptera was the most abundant order (11520 specimens), followed, in order, by Diptera (3362), Hymenoptera (2329) and Coleoptera (1154) (Table I).

Traps filled with salt water collected the greatest number of insects (7279 specimens, Table I). The mean number of specimens in salt water traps was not significantly higher than in ethylene glycol traps, but there were significantly more insects collected in either salt water traps or ethylene glycol

TABLE I. Total number of specimens of selected taxa collected in each preserving fluid.

Order	Preserving fluid			Total specimens
	Ethylene glycol	Propylene glycol	Salt water	
Coleoptera	397	462	295	1154
Diptera	1108	821	1433	3362
Homoptera	3744	3021	4755	11520
Hymenoptera	904	629	796	2329
Total specimens	6153	4933	7279	18365

traps than in propylene glycol traps (Fig. 1). There was also a significant difference between ethylene glycol and propylene glycol (Fig. 1).

Catches in the fluids differed by order. Coleoptera were most abundant in propylene glycol traps (462 specimens, Table I) followed, in order, by ethylene glycol and salt water (Table I). The mean number of Coleoptera per trap was not significantly higher in propylene glycol than in ethylene glycol, although all other differences were significant (Fig. 2).

Diptera and Homoptera were most abundant in salt water traps (1433 and 4755 specimens, respectively, Table I), followed by ethylene glycol and propylene glycol. Mean numbers of specimens for both orders were significantly higher in salt water than in either ethylene glycol or propylene glycol (Figs. 3–4). There was no significant difference between the two glycol fluids for Diptera (Fig. 3), but differences in mean numbers of specimens were significant between all three fluids for Homoptera (Fig. 4).

ALL ORDERS			
	EG	PG	SW
EG	175.8	*	-
PG		143.8	*
SW			207.9

1

COLEOPTERA			
	EG	PG	SW
EG	11.3	-	*
PG		13.2	**
SW			8.4

2

DIPTERA			
	EG	PG	SW
EG	31.6	-	*
PG		23.5	*
SW			40.9

3

HOMOPTERA			
	EG	PG	SW
EG	106.9	**	*
PG		86.3	*
SW			135.8

4

FIGURES 1–4. Mean numbers of specimens collected in each fluid, with statistical comparison ween fluids (- = not significantly different, $p>0.05$; * = significantly different, $p<0.05$, ** = highly significantly different, $p<0.0001$). 1, all orders combined; 2, Coleoptera; 3, Diptera; 4, Homoptera. Abbreviations: EG = ethylene glycol; PG = propylene glycol; SW = salt water.

HYMENOPTERA			
	EG	PG	SW
EG	25.8	*	-
PG		20.8	-
SW			22.7

5

CARABIDAE			
	EG	PG	SW
EG	3.0	-	-
PG		2.77	-
SW			3.28

6

CHLOROPIDAE			
	EG	PG	SW
EG	8.48	-	*
PG		9.48	*
SW			15.22

7

SPHAEROCERIDAE			
	EG	PG	SW
EG	4.88	*	-
PG		2.94	-
SW			3.54

8

FIGURES 5–8. Mean numbers of specimens collected in each fluid, with statistical comparison between fluids (- = not significantly different, $p>0.05$; * = significantly different, $p<0.05$, ** = highly significantly different, $p<0.0001$). 5, Hymenoptera; 6, Carabidae; 7, Chloropidae; 8, Sphaeroceridae. Abbreviations: EG = ethylene glycol; PG = propylene glycol; SW = salt water.

TABLE II. Mean number of specimens per trap (with standard deviation) for selected taxa collected in each preserving fluid.

Taxon	Preserving fluid		
	Ethylene glycol	Propylene glycol	Salt water
Coleoptera	11.34 ± 5.29	13.20 ± 7.31	8.42 ± 5.05
Carabidae	3.0 ± 2.07	2.77 ± 2.18	3.29 ± 2.67
Staphylinidae	3.66 ± 2.4	4.31 ± 3.09	1.17 ± 1.34
Diptera	31.66 ± 22.99	23.46 ± 16.12	40.94 ± 36.22
Chloropidae	8.49 ± 9.36	9.48 ± 10.29	15.23 ± 22.01
Colichopodidae	0.68 ± 1.02	0.08 ± 0.28	0.34 ± 0.80
Mycetophilidae	1.43 ± 1.70	1.06 ± 1.63	1.31 ± 1.83
Phoridae	2.37 ± 2.65	1.80 ± 1.78	4.83 ± 6.55
Sphaeroceridae	4.89 ± 3.45	2.94 ± 3.16	3.54 ± 2.78
Hymenoptera	25.83 ± 8.72	20.8 ± 8.75	22.74 ± 11.67
Apoidea	0.63 ± 0.88	0.11 ± 0.40	0.17 ± 0.38
Braconidae	0.60 ± 1.03	0.29 ± 0.51	0.40 ± 0.65
Chalcidoidea	1.63 ± 1.72	0.86 ± 1.03	1.2 ± 1.21
Ichneumonidae	0.69 ± 0.87	0.20 ± 0.47	0.46 ± 0.70
Proctotrupoidea	2.09 ± 1.7	1.37 ± 1.63	0.89 ± 0.9
Homoptera	106.97 ± 35.30	86.31 ± 37.63	135.86 ± 52.39
Cicadellidae	104.08 ± 35.28	83.66 ± 37.68	131.66 ± 52.32

Hymenoptera were most abundant in ethylene glycol traps (904 specimens, Table I), followed by salt solution and propylene glycol. Mean numbers of specimens were not significantly higher in ethylene glycol than in salt water, or in salt water than in propylene glycol (Fig. 5). There was a significant difference between ethylene glycol and propylene glycol.

Although the relative abundance of many families in the three fluids corresponded to that of the order (Table II), there were deviations from the pattern for some individual families. Carabidae (Coleoptera), for example, were most abundant in salt water, followed by ethylene glycol and propylene glycol (Fig. 6); however, none of these differences was significant. Chloropidae (Diptera) were significantly more abundant in salt water than in either ethylene glycol or propylene glycol (Fig. 7). Sphaeroceridae (Diptera) were most abundant in ethylene glycol, although there was no significant difference between this and salt water, or between salt water and propylene glycol (Fig. 8).

The difference in abundance of some taxa between the fluids was greater at different times during the course of the sampling period. The most pronounced example of this was in the Diptera where, although the relative ranking of the three fluids remained the same throughout the study, the abundance of flies became much higher in salt water relative to the glycols as the sampling period went on (Fig. 9).

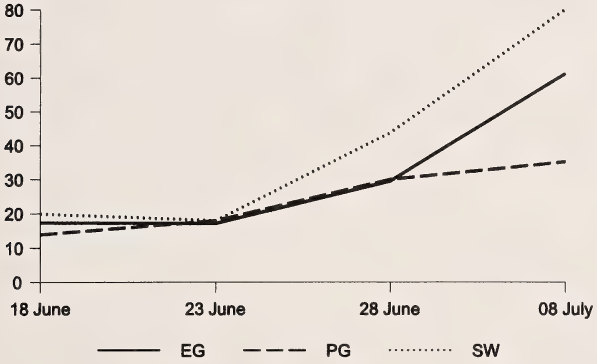

FIGURE 9. Changes in mean number of Diptera specimens per collecting fluid over sampling period. Abbreviations: EG = ethylene glycol; PG = propylene glycol; SW = salt water.

Discussion

Our results suggest that salt water is the most effective fluid for collecting at the ordinal level. Salt water traps had higher numbers of both Diptera and Homoptera, and were not statistically different from ethylene glycol traps for Hymenoptera. Only Coleoptera were collected in lower numbers in salt water traps, being most abundant in propylene glycol traps. Conversely, propylene glycol was the least effective fluid for Diptera, Homoptera and Hymenoptera.

While it is obvious that there are differences between the fluids, it is difficult to explain why. Previous studies have shown that colour is a factor in determining the effectiveness of pan traps. Many insects, especially phytophagous taxa, show a stronger attraction to yellow traps (Kirk 1984). The yellow colour of the traps was clearly visible through the salt water in our study, the ethylene glycol was greenish-yellow and the propylene glycol was pale pink. All traps were readily visible from above and flying insects may have responded to the colour of the fluids.

Both glycol fluids have a definite odour but we are not aware of any quantitative studies on the response of insects to these odours. The attractiveness of traps baited with carrion or decaying organic material for saprophagous insects is indicative of the role that odour plays in attraction of insects to a trap. Perhaps the odour of the glycol fluids has a slight repellent effect to taxa such as Diptera that results in lower catches.

The higher viscosity of ethylene glycol and propylene glycol compared to salt water is apparently not a factor in reducing the catch of small insects. The high numbers of microhymenoptera and some of the smaller Diptera in the glycol fluids (Table II) are evidence of the ability of these fluids to trap and retain very small insects.

Despite the quantitative differences demonstrated in our study, factors such as environmental conditions may play a role in determining which preserving fluid is most desirable for a particular sampling program. Salt water evaporates more quickly than either of the glycol fluids; thus, salt water traps are inadvisable when traps will be left unattended for long periods of time, or in dry, hot and/or windswept habitats where evaporation is faster. Covering the trap reduces evaporation, but the negative effects on the number and diversity of insects collected may outweigh the benefits (Spence and Niemalä 1994). Excessive rain will dilute the salt solution, decreasing the preservative effect of the salt and increasing decomposition of specimens. Ethylene glycol and propylene glycol may be considerably diluted with water before their preservative effect is lost.

Toxicity is another consideration in trap fluid choice. The replacement of ethylene glycol with propylene glycol in pan traps (and in some brands of automotive antifreeze) is a response of the higher toxicity of the former to vertebrates. Mochida and Gomyoda (1987) found that ethylene glycol is more toxic than propylene glycol to human cell cultures. Despite its lower toxicity, propylene glycol still represents a poisoning hazard to vertebrates. The sweet odour and taste of both glycol fluids contributes to the danger; animals are attracted to the fluids and drink from traps when possible. Marshall and Dory (1990) found that dogs were not particularly attracted to the taste of glycols unless they were deprived of food or water, although water deprivation may be a relatively common occurrence in drier habitats where pan traps may be used. The use of salt water in traps avoids the toxicity problems associated with the other fluids, and it may be the preferable fluid in situations where access to the traps by vertebrates is particularly likely.

Although a quantitative difference between the three preserving fluids was demonstrated, additional research would be desirable to investigate further these differences. Standardizing the colour of the fluids may determine if colour is a major factor responsible for differential collection rates. Also, studies in different habitats such as forests or more arid grasslands may give different results based on differences in the insect fauna. Finally, the possibility that insects respond in different ways to preserving fluids as the season progresses, as seen in Fig. 9, may be worth further study. Although pan traps are standard equipment in many insect sampling programs, additional simple studies like this one may help us to understand more clearly how that equipment works, and what factors affect its performance.

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DO TILLAGE REGIMES AND CROP TYPES INFLUENCE TERRESTRIAL ISOPOD DIVERSITY? (WITH A PRACTICAL KEY TO IDENTIFICATION OF SPECIES IN NORTHEASTERN NORTH AMERICA)

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Abstract

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Of the 18 species of isopods known from Ontario and for which a key is provided, only four were captured in our survey of farm fields: *Metoponorthus pruinosus* Budde-Lund, *Porcellio scaber* Latreille, *Porcellio laevis* Latreille, and *Trachelipus rathkei* Brandt (the most common). Pit fall trapping suggests that tillage, from conventional to no-till, affects isopod species richness, with conventional tillage having greater richness than no-till. A practical key is provided to the terrestrial Isopoda of southwestern Ontario's farmland.

Introduction

Most terrestrial isopods (woodlice) desiccate easily, but have protective physiological and behavioural traits. Physiological adaptations include: a water-resistant cuticle to prevent tissue transpiration, highly developed pleopodal lungs that eliminate water loss during respiration, and a marsupium which holds the developing young in a moist environment (Warburg 1987; Oliver and Meechan 1993). They also have behavioural traits that include: aggregation during dry weather to retain moisture in the centre of the mass (Davis 1984), negative photo-taxis (McQueen 1976), and attraction to moisture and humidity (Warburg 1987; Oliver and Meechan 1993). Thus, woodlice mostly inhabit dark, dank places such as under logs and stones, and on forest floors. Variations in these adaptations have even allowed some species to inhabit drier areas like deserts, basements, within walls, and farm fields (Warburg 1987).

Tillage, the process of turning the soil and incorporating organic litter into it, is an important agricultural practice. The main types of tillage used in southern Ontario are: high (mold board), medium (chisel plough) and no (conservation) tillage. High tillage penetrates approximately twice as far as medium tillage. No tillage involves seeding with minimal disturbance (Oryokot et al. 1997). Fields under high and medium tillage, in contrast to those under conservation tillage, lack distinguishable soil horizons, have less organic detritus on top and are much drier (Allmaras and Dowdy 1985). These various practices are thought to affect organisms, such as isopods, that live in the soil, in different ways (Davis 1984). Our study was made in conjunction with broader ecological research on the effects of tillage on ground beetles (Coleoptera: Carabidae) (Belaoussoff, in prep.) and weeds (Murphy et al., in prep.).

Our first objective was to assess how tillage affects isopod abundance and species richness. Because isopods prefer dark, detritus-rich habitats, our first hypothesis was that untilled fields have higher isopod species richness and abundances than do tilled fields. Secondly, we wanted to detect the effect of crop type on isopod richness. The fields we studied were planted with corn, wheat and bean. Based on several studies that have shown that monocotyledonous leaves can be toxic to woodlice (Warburg 1987), we hypothesize that bean fields have the highest isopod species richness and abundance.

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Materials and Methods

The samples were collected by pitfall trapping. The traps were white, plastic containers, 10 cm deep and with a diameter of 15 cm. The pots were buried in the ground so that the lip of the pot was level with the surface of the ground. The traps were laid out in transects; the first was set out at the field boundary and the six others were placed along a transect 1 m, 2 m, 4 m, 8 m, 16 m, and 32 m out from the fringe. They were filled with water and a few drops of household dish detergent to break the surface tension. In total there was one transect of 7 traps per study site.

Samples were collected once every seven days from 17 June to 14 August 1997. All captured invertebrates were immediately transferred to 70% ethanol and stored at room temperature, until they could be identified. Prior to identification, the samples were cleaned with water and all isopods were removed, identified and stored in 70% ethanol in glass vials.

The study was on farms in southwestern Ontario near Ayr and Drumbo. All fields had sandy loam soil and were bounded by riparian forests. The crop type and tillage regimes of the fields are outlined in Table I. The conservation and high tillage fields were near Drumbo on two separate farms, and the medium tillage fields were on one farm near Ayr.

TABLE I. The tillage regimes and crop types of the fields used. All the no-till (conservation) fields (i.e. G1–G5), and the high till (mold board) fields (i.e. C1 and C3) were located in farms in Drumbo; all the medium tillage (chisel plough) fields were located on a farm in Ayr. M.p. refers to *Metoponorthus pruinosus*, P.s. to *Porcellio scaber*, P.l. to *P. laevis* and T.r. to *Trachelipus rathkei*.

Field	Tillage	Crop type	Total abundance of M.p.	Total abundance of P.s.	Total abdundance of P.l.	Total abundance of T.r.	Species richness	Mean abundance per trap
G1	no	corn	0	0	1	112	2	1.8
G2	no	soy	0	0	0	130	1	2.1
G3	no	corn	0	0	0	151	1	2.8
G4	no	wheat	0	3	3	403	3	9.7
G5	no	soy	0	0	13	559	2	10.8
P4	medium	corn	2	0	29	249	3	4.6
P5	medium	soy	4	0	12	206	3	4.0
P6	medium	wheat	20	7	118	616	4	15.5
C1	high	wheat	0	3	40	463	3	10.3
C3	high	soy	4	2	65	644	4	11.4

For each field the species richness and abundance for isopods were determined. The total abundance and abundance per trap were calculated. Average abundance per trap was used for comparisons, because mammal activity disrupted some traps in some fields making sample numbers unequal. Species richness was determined for the entire trapping programme. Sign tests were used to decide whether tillage or crop type significantly affected abundance or species richness.

Our data were not applicable to examining the interactions between tillage and crop, which would constitute a major study in itself.

The specimens were identified using the key we developed as adapted from Jass and Klausmeier (1990), Oliver and Meechan (1993), Van Name (1936) and Wright (1995). This practical key is intended for use by ecologists who wish to identify terrestrial isopods in northeastern North America. We advocate that identifications made using our key be double-checked against taxonomic descriptions and formally presented keys.

Results

Although 18 isopod species (see key) have been noted for occurrence in southern Ontario's agricultural fields as representative of similar habitats in northeastern North America, only four species were captured throughout the experiment: *Metoponorthus pruinosus* Budde-Lund, *Porcellio scaber* Latreille, *Porcellio laevis* Latrielle, and *Trachelipus rathkei* Brandt, all in the suborder Oniscodea. By far the most common species was *T. rathkei*. *P. laevis* was the second most abundant while *M. pruinosus* and *P. scaber* were both infrequently captured. The fields with the highest species richness and abundances per trap were high tillage with soy-bean (C3: 4 species and 11 average abundance of isopods per trap), and medium tillage with wheat (P6: 4 and 15.5 average abundance of isopods per trap) (Table I).

Richness values were low, ranging from 1 to 4 species. Overall, samples from low tillage had lower values (1 to 3 species) than did those from more intensively tilled fields (3 to 4 species) (Table I). The results of the sign test applied to pair-wise comparisons of richness within crop, but between tillage, produced a probability of 0.03 that the effects of tillage were the same (Table II). The same test applied to mean abundance per trap produced a probability of 0.03 (Table II).

To assess if crop type affects species richness and abundance, we made pair-wise binomial tests by crop type regardless of tillage under the hypothesis that soy-beans would favour isopods. The results of none of these tests were significant (P = 0.23 for richness and P = 0.16 for abundance).

TABLE II. Ratios used for sign tests to decide whether or not tillage, and whether or not crop type, significantly affected species richness or abundance. The first number in each ratio is the species richness or abundance for fields in the rows, the second for fields in the columns.

Low tillage	Medium tillage			High tillage	
FIELDS	Corn (P4)	Soy (P5)	Wheat (P6)	Soy (C3)	Wheat (C1)
	Richness				
Corn (G1)	2:3 (-)				
Corn (G3)	1:3 (-)				
Bean (G2)		1:3 (-)		1:4 (-)	
Bean (G5)		2:3 (-)		2:4 (-)	
Wheat G4)			3:4 (-)		3:3 (=)
	Mean abundance per trap				
Corn (G1)	1.8:4.6 (-)				
Corn (G3)	2.8:4.6 (-)				
Bean (G2)		2.1:4.0 (-)		2.1:11.4 (-)	
Bean (G5)		10.8:4.0 (+)		10.8:11.4 (-)	
Wheat (G4)			9.7:15.5 (-)		9.7:10.3 (-)

Discussion

The four species collected over the two months of trapping were *M. pruinosus, P. scaber, P. laevis* and *T. rathkei*. The high numbers of *T. rathkei*, as compared to those of the other three species was expected. Van Name (1936) reports that *T. rathkei* is by far the most abundant isopod in southern Ontario agricultural fields and that *M. pruinosus, P. scaber* and *P. laevis* are relatively less common, but scattered. Of the other species commonly captured in southern Ontario farms and forests, it is surprising that *Armadillidium vulgare* Latrielle was not captured (Jass and Klausmeier 1990) because it is found frequently in southern Ontario farm lands (Van Name 1936). Its absence from the corn and wheat fields may be explained because corn and wheat are both monocotyledons and, according to Warburg (1987), monocotyledon's leaves are toxic to this species.

The between-fields differences in species richness were dependent on the tillage regime, but the differences are counter to our hypothesis. The fields with conservation tillage had significantly fewer isopod species than did the fields with medium and high tillage. These findings are supported by other authors' results. In a study on the re-naturalization of old landfill sites in Britain, Judd and Mason (1995) discovered that areas that were highly disturbed (had only been covered with topsoil and left for 4 years) had higher species richness than did fields that were less disturbed (had been covered with topsoil and left for 12 years). Also, in Italy, Paoletti et al. (1995) compared soil macro-fauna (such as isopods, earthworms, carabid beetles, etc.) species richness in apple orchards (treated with pesticides and herbicides and mowed three to four times a season) to species richness in a mature deciduous forest. Those studies indicated that the more disturbed orchards had higher species richness for isopods than did the less disturbed forest.

The hypothesis that, for isopods, the untilled fields we sampled had greater abundances of isopods than the tilled fields is not supported. Tillage did not affect abundance. As mentioned above, the species we captured are adapted to dry, compacted and detritus-poor habitats (Oliver and Meechan 1993). The hypothesis that the bean fields, because of their higher moisture, shade, and organic litter layer, would have higher species richness and abundance than the corn and wheat fields was not supported. Bean crop type did not have a significant affect on woodlice species richness nor abundance.

Acknowledgments

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A Practical Key to the Terrestrial Isopoda that may be found on Southwestern Ontario Farmland as Representative of Northeastern North America

1a Flagellum of second antenna with 10 or more articles; rami of uropod very long and slender; Family **Ligiidae** ... **2**

1b Flagellum of second antenna with five or fewer articles; rami of uropod rather short and stout ... **3**

2 The only genus belonging to this family in Southwestern Ontario is ***Ligidium*** of which there are three species in the area:

    I) 8 mm long, dark eyes, antennae of 15 segments and trail back over the body, reddish brown in and mottled with yellow ... ***L. longicaudatum***

    II) 9 mm long, large light eyes, antennae of 15 segments, but held perpendicular to the body, dark brown, with irregular dark patches and pale edges ... ***L. hypornorum***

    III) 9 mm long, antennae of 15 segments, generally light brown and mottled, no well marked dorsal streak ... ***L. elrodii***

3a Flagellum markedly more slender than basal segments of second antenna, composed of three to six indistinct articles ... **4**

3b Flagellum nearly as stout as basal segments of second antenna, composed of two to four distinct articles ... **10**

4 Eye of one to three ocelli or absent; Family **Trichoniscidae** ... **5**

5a Eye of three ocelli ... **6**

5b Eye of a single ocellus ... **7**

6 Dorsal surface smooth and shiny ... ***Trichoniscus***

    I) Body mottled reddish brown ... ***T. pusillus***

    II) Body whitish ... ***T. pygmaeus***

7a Dorsal surface tuberculate ... **8**

7b Dorsal surface smooth and shiny ... ***Hyloniscus***

    I) Only one species, 7mm ... ***H. riparius***

8a Dorsal surface with tubercles distributed randomly or in transverse rows; normally coloured ... **9**

8b Dorsal surface with tubercles in distinct longitudinal rows ... ***Haplophthalmus***

    I) Only one species, pleon lacks any tergal ridges ... ***H. danicus***

9 Rosy pink in colour; endopodite of first pleopod of male long and spoon-shaped ... ***Androniscus***

    I) Only one species, sculptural tubercles prominent but with sensory spines, not pegs, eyes large in comparison to head ... ***A. dentiger***

10a Eye compound of many ocelli, body usually coloured, flagellum of second antenna of two articles ... **13**

10b Eye compound of many ocelli, body usually coloured, flagellum of three articles, family **Oniscidae** (in part) ... **11**

11a Head with distinct anterolateral processes; body elliptical; outline of pleon smoothly continuous with that of pereion ... **12**

11b Head without anterolateral processes; body elongate; pleon abruptly narrower than pereion ... ***Philoscia***

    I) Only one species, highly patterned colouration ... ***P. muscorum***

12 Body broad, rather flattened; anterolateral processes of head prominent; telson elongate ... ***Oniscus***

    I) Only one species, perion-pleon junction continuous ... ***O. asellus***

13a Uropods extend beyond telson, which is produced; Family **Oniscidae** (in part) **14**

13b Uropods not extending beyond telson, which is broadly truncate **17**

14a Outline of pereion and pleon continuous; front margin produced into a median lobe (when viewed from above) **15**

14b Pleon distinctly narrower than pereion; front margin of head nearly straight (when viewed from above) .... ***Metoponorthus***

   I) Only one species; uniformly bluish grey (occasionally pinkish) and with a surface bloom .... ***M. pruinosus***

15a Median lobe of head sharp and pointed (when viewed from above); body quite convex, can be rolled into a ball .... ***Cylisticus***

   I) One species only; five pairs of pleopodal lungs; body brownish grey with distinctive paler or orange uropod bases .... ***C. convexus***

15b Median lobe of head rounded (when viewed from above); body moderately flattened, cannot be rolled into a ball **16**

16a Exopodites of all 5 pleopods with tracheae (white patches) .... ***Trachelipus***

   I) Only one species; distinctive pattern of submedian double row of dark mottling and pale subepimeral flashes .... ***T. rathkei***

16b Exopodites of only first two pleopods with tracheae ....***Porcellio***

   I) Uniformly grey or weakly mottled with light edges, strongly sculptured with prominent tubercles .... ***P. scaber***

   II) Dorsal surface smooth and glossy, generally brownish to light grey with some median lateral mottling .... ***P. laevis***

   III) Mottled brown with a dark median zone bordered with bright yellow patches and a dark almost black head .... ***P. spinicornis***

17 External ramus of uropod broad and flat, hinged to basal segment and contributing to posterior outline of body; internal ramus small, attached ventrally; Family **Armadillidiidae** One genus ....***Armadillidium***

   I) Uniform grey, seventh perepod without a knob on basis, 18 mm ..... ***A. vulgare***

   II) Scutellum distinctly raised above the dorsal surface of the head, grey or brownish grey, 12 mm .... ***A. nasatum***

The above key is a compilation of four different sources: Jass and Klausmeier (1990), Oliver and Meechan (1993), Van Name (1936), and Wright (1995).

CANADA MAYFLIES: A FAUNISTIC COMPENDIUM

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Abstract

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An account of 321 species of mayflies (Ephemeroptera) of Canada is provided and is based on the examination of previously unstudied material and on a comprehensive bibliographic review of initial records of all species (including synonyms and misidentifications) for each of the Canadian provinces and territories. Ninety-seven new provincial and territorial records of species are presented. *Apobaetis indeprensus* Day from Saskatchewan, *Plauditus cestus* (Provonsha and McCafferty) from Ontario, *Procloeon rivulare* (Traver) from Nova Scotia, *Procloeon viridoculare* (Berner) from Ontario, *Anepeorus simplex* (Walsh) from Ontario, and *Stenacron gildersleevei* (Traver) from Manitoba represent new, substantiated records for Canada. Checklists for each of the provinces and territories are given, and species included are annotated to indicate new records, endemism, type locality, and distribution outside of the province or territory and outside Canada. There are 102 species recorded for Alberta, 92 for British Columbia (two new records), 93 for Manitoba (two new records), 89 for New Brunswick (16 new records), 46 for Newfoundland Province (17 new records), 87 for Nova Scotia (14 new records), 52 for the Northwest Territories (one new record), 165 for Ontario (11 new records), 14 for Prince Edward Island (13 new records), 163 for Quebec (one new record), 82 for Saskatchewan (19 new records), and 28 for the Yukon Territory (one new record). Over 70% of the Canadian fauna was originally described from there. Only about 10% of the Canadian fauna is apparently endemic.

Résumé

Proc. ent. Soc. Ont. 129: 47-97

Un inventaire de 321 espèces d'Ephémères (Ephemeroptera) du Canada est présenté. Il est basé l'examen d'un matériel non étudié auparavant et sur une revue bibliographique d'ensemble des premières citations de toutes les espèces (y compris les synonymes et les erreurs d'identification) pour chacune des provinces et chacun des territoires canadiens. En outre, 97 citations nouvelles d'espèces, provinciales et/ou territoriales, sont présentées. Des citations nouvelles pour le Canada sont aussi établies : *Apobaetis indreprensus* Day au Saskatchewan, *Plauditus cestus* (Provonsha et McCafferty) en Ontario, *Procloeon rivulare* (Traver) en Nouvelle-Ecosse, *Procloeon viridoculare* (Berner) en Ontario, *Anepeorus simplex* (Walsh) en Ontario, et *Stenacron gildersleevei* (Traver) au Manitoba. Des listes sont dressées pour chaque province et territoire, dont les espèces sont annotée pour préciser : les citations nouvelles, l'endémisme, la localité-typique et la distribution à l'extérieur de la province ou de territoire ainsi qu'hors du Canada. En tout, 102 espèces sont répertoriées en Alberta, 92 en Colombie Britannique (dont deux citations nouvelles), 93 au Manitoba (deux citations nouvelles), 89 au Nouveau Brunswick (16 citations nouvelles), 46 sur la province de Terre-Neuve (17 citations nouvelles), 87 en Nouvelle Ecosse (14 citations nouvelles), 52 sur les Territoires de Nord-Quest (une citation nouvelle), 165 en Ontario (11 citations nouvelles), 14 sur l'Ile du Prince Edward (13 citations nouvelles), 163 au Québec (une citation nouvelle), 82 au Saskatchewan (19 citations nouvelles), et 28 su le Territoire du Yukon (une citation nouvelle). Plus de 70% de la faune du Canada a été originellement décrite de ces régions. Seulement 10% environ de la faune canadienne est apparemment endémique.

Introduction

The mayfly fauna of Canada is relatively species rich (321 species accounted for herein) considering the severe and often limiting far northern climatic conditions with restricted growing seasons that are present in a large portion of the country. This species richness is even more impressive when considering that nearly all of Canada was glaciated as recently as 10,000 years ago, and most present distributions in Canada are attributable to dispersal events and recolonization since that time. Aquatic habitats are, however, abundant throughout the country, and there has been a rich heritage of aquatic scientists who have worked on the fauna from both taxonomic and ecological perspectives.

The first descriptions and earliest report of mayflies from Canada were by Say (1824), wherein he described *Ephoron album* from Manitoba and *Siphlonurus alternatus* from the Northwest Territories (both originally as *Baetis*). Several other workers described species from Canada in the latter part of the 19th Century (Say 1839; Walker 1853; Hagen 1861; Provancher 1876, 1878; Eaton 1884–85). Sixteen of the species described from Canada in the nineteenth century remain valid today. Eight of those were described from Ontario, four from Quebec, two from Manitoba, one from Nova Scotia, and one from the Northwest Territories. There were, however, additional nineteenth century reports of another 16 species from Canada: two from Manitoba, seven from Ontario, eight from Quebec, two from Nova Scotia, two from Saskatchewan, and one from British Columbia (see Walker 1853; Hagen 1861, 1863; Eaton 1871, 1885; and Provancher 1876).

It was Walker (1853), in his study of specimens housed in the British Museum at that time, who made the earliest significant contribution to mayfly faunistics in Canada. Walker described 17 species from Canada. Two of those names proved to be homonyms and are known today as *Drunella walkeri* Eaton and *Rhithrogena jejuna* Eaton, eight were later synonymized, and the seven that remain valid are some of the best known species in North America: *Ephemerella invaria*, *Ephemera simulans*, *Epeorus vitreus*, *Isonychia bicolor*, *Leptophlebia nebulosa*, *Paraleptophlebia debilis*, and *Siphloplecton basale*.

A remarkable 72% of the valid species known from Canada were originally described from there, yet most of these species also occur in the United States. The immense descriptive contribution to North American ephemeropterology by the Canadian John McDunnough, primarily in the 1920s and 1930s, is undoubtedly the reason for this. McDunnough described 171 species from Canada in some 33 papers (see References). Of the McDunnough species described from Canada, 134 remain valid, although two have been renamed because they were secondary homonyms, and 37 have thus far proven to be junior synonyms. The Canadians W.A. Clemens and F.P. Ide each described four valid species from Canada in the twentieth century. The 14 other twentieth century workers who have authored or co-authored valid species from Canada have named even fewer.

The first substantial faunal list of the Canadian mayfly fauna per se was that of McDunnough (1925a), wherein 134 mostly valid species were recorded country wide. Although a somewhat modified and useful Canadian list (especially for updated provincial records) was given by Walley (1927), nothing on that scale for the entire country has been compiled since that time, and this has been one of the primary motivations for the present study. There have been, however, considerable regional works in the twentieth century that have contributed significantly to the documentation of species distributions within Canada. Some notable recent examples include Scudder (1975) for British Columbia, Lehmkuhl (1976a) for Saskatchewan, Cobb and Flannagan (1980) and Harper and Harper (1981) for northern Canada, Flannagan and Flannagan (1982) for Manitoba, Larson and Colbo (1983) for Newfoundland, Petersen (1989) for New Brunswick and Nova Scotia, Dulude (1992) for Quebec, and Harper and Harper (1997) for the Yukon Territory.

The purpose of the present work has been to present a concise yet comprehensive inventory of all the species of Ephemeroptera in Canada. This includes a bibliographic account of the initial records of any species for any province or territory under any historical name attributable to the species, in addition to new records presented herein. It also includes a series of checklists for each province and territory, with numerous ancillary data annotated to the species. The study was in part instigated by numerous requests by users of Mayfly Central on the World Wide Web (http://www.entm.purdue.edu/entomology/mayfly/mayfly.html) for additional country data associated with the "Mayflies of North America" database.

Methods

Data presented here were compiled by 1) reviewing taxonomic literature wherein Canadian mayflies were described, 2) reviewing revisionary systematic literature dealing with genera that occur in Canada, 3) reviewing synoptic works on Ephemeroptera citing Canadian records, 4) reviewing regional faunal studies carried out in Canada, 5) reviewing limnological survey and macroinvertebrate ecology and toxicology studies carried out in Canada, 6) studying materials from Canada in the Purdue Entomological Research Collection, 7) soliciting new record data from colleagues who have recently made significant collections in Canada, and 8) accessing and identifying certain collections from Canada.

Record data are presented alphabetically by family, genus, and species. Author and year of publication of each species is given, but subspecies are not differentiated. For each species treatment the following is included: The provinces and territories in which it is known are given in bold abbreviation. For each province or territory noted for the species, the bases of that record are given in brackets, either as a bibliographic citation for the first record, or actual locale data for new records being presented. In a few instances, upgraded data serve as the basis of record data (for example, if data were assigned only to an unspecified species previously but can now be verified for a precise species). If the bibliographic data represent the original description of the species and the province or territory also encompasses the type locality of the species, "type" is indicated with the bibliographic citation. If the bibliographic data were given under a synonym or other form of the name, then that is also indicated. First records for all synonyms are given, and first records given under misidentifications are also indicated. New records include stage of mayfly, available locale information, date of collection, collector(s), and material location.

Province and territory abbreviations are as follows: **AB** = Alberta, **BC** = British Columbia, **MB** = Manitoba, **NB** = New Brunswick, **NF** = Newfoundland, **NS** = Nova Scotia, **NW** = Northwest Territories, **ON** = Ontario, **PE** = Prince Edward Island, **PQ** = Quebec, **SA** = Saskatchewan, and **YU** = Yukon Territory. Material locations cited are as follows: CSU = Colorado State University Entomological Collection, Fort Collins; PERC = Purdue Entomological Research Collection, Purdue University, West Lafayette, Indiana; RWG = R.W. Griffiths, private collection, Dutton, Ontario; SASK = University of Saskatchewan, Saskatoon, Saskatchewan.

The checklists include annotations by way of footnotes to species that indicate the following: newly reported provincial or territory records, newly reported Canada records, type localities, endemism both with respect to province and territory or country, occurrence in other parts of Canada, occurrence in the Palearctic, occurrence in Alaska, and occurrence in the conterminous United States.

Record Data Summary

In keeping with our intention of providing data useful in prioritizing future research on the faunistics of the Canada Ephemeroptera, certain statistics that can be derived from our results are summarized here. Of the 321 species reported below, six represent new records for Canada: *Apobaetis indeprensus* Day (Saskatchewan), *Plauditus cestus* (Provonsha and McCafferty) (Ontario), *Procloeon rivulare* (Traver) (Nova Scotia), *Procloeon viridoculare* (Berner), *Anepeorus simplex* (Walsh) (Ontario), and *Stenacron gildersleevei* (Traver) (Manitoba). Species numbers per province and territory are 102 for Alberta, 92 for British Columbia, 93 for Manitoba, 89 for New Brunswick, 46 for Newfoundland (27 for Newfoundland Island and 28 for Labrador), 87 for Nova Scotia, 52 for the Northwest Territories, 165 for Ontario, 14 for Prince Edward Island, 163 for Quebec, 82 for Saskatchewan, and 28 for the Yukon Territory. Ninety-seven new provincial and territorial records include two for British Columbia, two for Manitoba, 16 for New Brunswick, 17 for Newfoundland (and eight additional records for Labrador that were previously known from Newfoundland Island), 10 for Nova Scotia, one for the Northwest Territories, 11 for Ontario, one for Quebec, 19 for Saskatchewan, and one for the Yukon Territory.

Some 230 species were originally named from Canada. Of the 176 of these that remain valid, 54 were described from Quebec, 43 from Ontario, 40 from Alberta, 17 from British Columbia, nine from Manitoba, four from Nova Scotia, six from Saskatchewan, and three from the Northwest Territories. Thirty-one species are presently considered endemic to Canada. Four species are endemic to Alberta, two to British Columbia, three to Manitoba, one to the Northwest Territories, five to Ontario, four to Quebec, and one to Saskatchewan. Eleven Canadian species are also known from the Palearctic. Sixteen of the Canadian species are also known from Alaska, although the Alaskan fauna remains especially poorly known and undoubtedly more are shared than presently indicated. Some 282 species are shared by Canada and the conterminous United States.

Record Data

ACANTHAMETROPODIDAE

Analetris eximia Edmunds, 1972: **AB** [Barton (1980)]. **SA** [Lehmkuhl (1976b)].

AMELETIDAE

Ameletus bellulus Zloty, 1996: **AB** [Zloty (1996), type].
Ameletus browni McDunnough, 1933: **PQ** [McDunnough (1933c), type].
Ameletus celer McDunnough, 1934: **AB** [McDunnough (1934), type; McDunnough (1934) as *Ameletus alticolus* McDunnough, 1934, type]. **BC** [McDunnough (1934) as *Ameletus celeroides* McDunnough, 1934, type; McDunnough (1939) as *Ameletus tuberculatus* McDunnough, 1939, type; Scudder (1975)].
Ameletus cooki McDunnough, 1929: **AB** [Zloty (1996)]. **BC** [McDunnough (1935)].
Ameletus inopinatus Eaton, 1887: **NW** [Zloty (1996)].
Ameletus lineatus Traver, 1932: **PQ** [Dulude (1992)].
Ameletus ludens Needham, 1905: **ON** [Walley (1927)]. **PQ** [McDunnough (1925a)].

Ameletus majusculus Zloty, 1996: **AB** [Zloty (1996), type].

Ameletus oregonensis McDunnough, 1933: **AB** [Boerger and Clifford (1975)]. **BC** [Scudder (1975)]. **SA** [Zloty (1996)].

Ameletus pritchardi Zloty, 1996: **AB** [Zloty (1996), type]. **BC** [Zloty (1996)].

Ameletus shepherdi Traver, 1934: **BC** [McDunnough (1938) as *Ameletus querulus* McDunnough, 1938, type].

Ameletus similior McDunnough, 1928: **AB** [McDunnough (1928a), type]. **BC** [McDunnough (1935); Mayo (1952) as *Ameletus monta* Mayo, 1952, type].

Ameletus sparsatus McDunnough, 1931: **AB** [McDunnough (1931a), type]. **BC** [McDunnough (1935)]. **NW** [Wiens et al. (1975) as *Ameletus* prob. *sparsatus*].

Ameletus subnotatus Eaton, 1885: **AB** [McDunnough (1925a)]. **BC** [Zloty (1996)]. **MB** [Zloty (1996)]. **NB** [Zloty (1996)]. **NF** [Newfoundland Island, Zloty (1996)]. **ON** [Zloty (1996)]. **PQ** [Harper (1989)].

Ameletus suffusus McDunnough, 1936: **AB** [Zloty (1996)]. **BC** [McDunnough (1936b), type].

Ameletus tertius McDunnough, 1938: **NF** [Labrador: adult, stream entering Moosehead Lake, Hwy 500, E of Labrador City, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, Miron River, Hwy 500, E of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, West Metchin River, Hwy 500, 32 mi E of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [McDunnough (1938), type]. **PQ** [McDunnough (1932a) as *Ameletus* sp.; Dulude (1992)].

Ameletus validus McDunnough, 1923: **AB** [McDunnough (1923), type]. **BC** [McDunnough (1935)].

Ameletus vancouverensis McDunnough, 1933: **BC** [McDunnough (1933b), type].

Ameletus velox Dodds, 1923: **AB** [McDunnough (1925a)]. **BC** [Walley (1927); McDunnough (1936b) as *Ameletus connectus* McDunnough, 1936, type; McDunnough (1939) as *Ameletus connectinus* McDunnough, 1939, type].

Ameletus vernalis McDunnough, 1924: **AB** [Zloty (1996)]. **BC** [McDunnough (1924a), type].

Ameletus walleyi Harper, 1970: **ON** [Harper (1970), type].

AMETROPODIDAE

Ametropus albrighti Traver, 1935: **SA** [Lehmkuhl (1976a)].

Ametropus neavei McDunnough, 1928: **AB** [McDunnough (1928a), type]. **NW** [Cobb et al. (1995)]. **SA** [Allen and Edmunds (1976)].

ARTHROPLEIDAE

Arthroplea bipunctata (McDunnough), 1924: **NB** [Whiting (1992)]. **NS** [Petersen (1989)]. **NW** [Wiens et al. (1975) as *Arthroplea* sp.; Cobb and Flannagan (1980)]. **ON** [Walley (1927) as *Cinygma*]. **PQ** [McDunnough (1925a, 1925b) as *Cinygma*].

BAETIDAE

Acentrella insignificans (McDunnough), 1926: **AB** [Morihara and McCafferty (1979) as *Baetis*]. **BC** [McDunnough (1926b) as *Baetis*, type]. **NW** [Moore (1977) as *Baetis* sp.]. **SA** [larvae, South Saskatchewan River, ferry E of Hague, 20 July, 8, 17 August 1972, D.H. Smith (SASK); South Saskatchewan R, ferry N of Birch Hills, 7 June, 24 August, 14 September 1972, D.H. Smith (SASK); South Saskatchewan River, Clarksboro Ferry, 29 May, 9 June 1972, D.H. Smith (SASK); South Saskatchewan River, ferry 4 mi E of Warren, D.H. Smith (SASK);

South Saskatchewan River, Lemsford Ferry, 14 July 1971, D.M. Lehmkuhl; North Saskatchewan River, 10 mi E Prince Albert, Cecil Ferry, 1 June 1971, D.H. Lehmkuhl (SASK)]. **YU** [Harper and Harper (1997)].

Acentrella lapponica Bengtsson, 1912: **NF** [Labrador: Harper and Harper (1981) as *Baetis*]. **NW** [McDunnough (1936a) as *Baetis*]. **PQ** [Harper and Harper (1981) as *Baetis*].

Acentrella turbida (McDunnough), 1924: **AB** [McDunnough (1924a) as *Pseudocloeon*, type]. **BC** [McCafferty et al. (1994)]. **MB** [Flannagan et al. (1990) as *Pseudocloeon*]. **NB** [larvae, Miramichi River, 2 September 1950, 17 August 1950, E.L. Bousefield (PERC)]. **ON** [Walley (1927) as *Pseudocloeon carolina* (Banks), 1924]. **PQ** [McDunnough (1925b) as *Pseudocloeon carolina* (Banks), 1924]. **SA** [larvae, Meeyomoot River, at Hwy 165, 17 June 1971, D.H. Smith (SASK); South Saskatchewan River, 1 mi upstream from Saskatoon, 10 August 1970, D.M. Lehmkuhl (SASK); North Saskatchewan River, ferry 10 mi E of Prince Albert, 21 September 1972 (SASK)].

Acerpenna akataleptos (McDunnough), 1926: **AB** [McDunnough (1926a) as *Baetis*, type].

Acerpenna macdunnoughi (Ide), 1937: **NB** [Petersen (1989) as *Baetis*]. **NF** [Newfoundland Island: Larson and Colbo (1983) as *Baetis*. Labrador: larva, Miron River, Hwy 500, E of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Petersen (1989) as *Baetis*]. **ON** [Flannagan and Cobb (1995)]. **PQ** [Ide (1937) as *Baetis*, type].

Acerpenna pygmaea (Hagen), 1861: **MB** [Friesen et al. (1980) as *Baetis*; Friesen et al. (1980) as *Baetis harti* McDunnough, 1924]. **NB** [Petersen (1989) as *Baetis*]. **NF** [Newfoundland Island: Larson and Colbo (1983) as *Baetis*]. **NS** [Petersen (1989) as *Baetis*]. **NW** [Cobb and Flannagan (1980) as *Baetis*]. **ON** [McDunnough (1925a) as *Baetis*]. **PQ** [Hagen (1861) as *Cloe*, type]. **SA** [adults, North Saskatchewan River, ferry 10 mi E of Prince Albert, 13, 14 July 1981, D.M. Lehmkuhl (SASK)].

Apobaetis indeprensus Day, 1955: **SA** [larvae, South Saskatchewan R, Ferry N of Lemsford, 10 August 1971, D.M. Lehmkuhl (SASK); adult, South Saskatchewan River, ferry N of Birch Hills, 7 June 1972, D.H. Smith (SASK)].

Baetis bicaudatus Dodds, 1923: **AB** [Morihara and McCafferty (1979)]. **BC** [Walley (1927)]. **NW** [Moore (1977)]. **YU** [Cobb et al. (1995)].

Baetis brunneicolor McDunnough, 1925: **MB** [Morihara and McCafferty (1979)]. **NB** [Eidt (1975)]. **NS** [Petersen (1989)]. **ON** [McDunnough (1925d), type]. **PE** [larvae, Prince Co., Miminegash River, Hwy 151, 19 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1932a)]. **SA** [larvae and adults, North Saskatchewan River, ferry 10 mi E of Prince Albert (SASK); adults, River 37 mi N of Green Lake, 10 July 1974, L. Dosdall (SASK)].

Baetis bundyae Lehmkuhl, 1973: **BC** [larvae, North Garnet Creek at old mine road, 7 km W of Endako, 15 June 1992, E. Whiting (PERC)]. **MB** [Harper and Harper (1981) as *Baetis macani bundyae*]. **NF** [Labrador: Harper and Harper (1981) as *Baetis macani bundyae*]. **NW** [Lehmkuhl (1973), type]. **PQ** [Harper and Harper (1981) as *Baetis macani bundyae*]. **YU** [Harper and Harper (1981) as *Baetis macani bundyae*; Harper and Harper (1997)].

Baetis flavistriga McDunnough, 1921: **MB** [Morihara and McCafferty (1979)]. **NB** [Eidt (1975) as *Baetis levitans* McDunnough, 1925; Petersen (1989)]. **NF** [Newfoundland Island: Larson and Colbo (1983)]. **NS** [Petersen (1989)]. **NW** [Cobb and Flannagan (1980)]. **ON** [McDunnough (1921), type; McDunnough (1923) as *Baetis nanus* McDunnough, 1923, type; McDunnough (1923) as *Baetis phoebus* McDunnough, 1923, type; Walley (1927) as *Baetis cingulatus* McDunnough, 1925; Walley (1927) as *Baetis levitans* McDunnough, 1925; Walley (1927) as

Baetis pallidula McDunnough, 1924; Griffiths (1996)]. **PE** [larvae, Prince Co., Miminegash River, Hwy 151, 19 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1925a, 1925b); McDunnough (1925a) as *Baetis phoebus* McDunnough, 1923; McDunnough (1925b) as *Baetis cingulatus* McDunnough, 1925, type; McDunnough (1925b) as *Baetis levitans* McDunnough, 1925, type]. **SA** [adults, North Saskatchewan River, ferry 10 mi E of Prince albert, 24 August 1971, D.H. Smith (SASK); Crean River at Hwy 2, 4 June 1974, D.M. Lehmkuhl (SASK)].

Baetis foemina McDunnough, 1936: **NW** [McDunnough (1936a), type].

Baetis hudsonicus Ide, 1937: **MB** [Ide (1937), type]. **ON** [larvae, Kenora, trib. Breakneck Creek, 26 June 1990, W.B. Morton (PERC)]. **SA** [larvae, Saskatchewan River at mile 2 of Hwy 165, 17 June 1971, D.H. Smith (SASK)].

Baetis intercalaris McDunnough, 1921: **MB** [McDunnough (1925a)]. **NB** [Morihara and McCafferty (1979)]. **NS** [Petersen (1989)]. **ON** [McDunnough (1921), type]. **PQ** [McDunnough (1925a)].

Baetis moffatti Dodds, 1923: **AB** [McDunnough (1925a)]. **BC** [Walley (1927)].

Baetis parallelus Banks, 1924: **AB** [Walley (1927)]. **BC** [Walley (1927)].

Baetis persecutor McDunnough, 1939: **AB** [Hamilton and Clifford (1983)]. **BC** [McDunnough (1939), type].

Baetis pluto McDunnough, 1925: **MB** [Flannagan et al. (1990)]. **NB** [Eidt (1975)]. **NS** [Petersen (1989)]. **ON** [Walley (1927)]. **PQ** [McDunnough (1925b), type; McDunnough (1925b) misidentified in part as *Baetis rusticans* McDunnough, 1925].

Baetis rusticans McDunnough, 1925: **NB** [Eidt (1975)]. **ON** [Walley (1927)]. **PQ** [McDunnough (1925b), type].

Baetis tricaudatus Dodds, 1923: **AB** [McDunnough (1925a) as *Baetis intermedius* Dodds, 1923; Clifford (1969)]. **BC** [McDunnough (1925a); Walley (1927) as *Baetis intermedius* Dodds, 1923; McDunnough (1938) as *Baetis jesmondensis* McDunnough, 1938, type]. **MB** [Ide (1937) as *Baetis vagans* McDunnough, 1925; Morihara and McCafferty (1979)]. **NB** [Eidt (1975) as *Baetis vagans* McDunnough, 1925; Petersen (1989)]. **NF** [Newfoundland Island: Larson and Colbo (1983); Labrador: larvae, Raft River, Hwy 500, 34 mi N of Churchhill Falls, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); larvae, Trout Brook, Hwy 510, Pinware, 6 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Morihara and McCafferty (1979)]. **NW** [Wiens et al. (1975) as *Baetis* prob. *vagans* McDunnough, 1925]. **ON** [Walley (1927) as *Baetis incertans* McDunnough, 1925; Walley (1927) as *Baetis vagans* McDunnough, 1925; Morihara and McCafferty (1979)]. **PE** [larvae and adults, Prince Co., Tignish River, Hwy 158, 19 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1925b) as *Baetis incertans* McDunnough, 1925, type; McDunnough (1925b) as *Baetis vagans* McDunnough, 1925, type; Morihara and McCafferty (1979)]. **SA** [Lehmkuhl (1976a) as *Baetis vagans* McDunnough, 1925; Dosdall and Lehmkuhl (1989a, 1989b)]. **YU** [Cobb et al. (1995)].

Callibaetis ferrugineus (Walsh), 1862: **AB** [McDunnough (1925a) as *Callibaetis tessellatus* (Hagen), 1861; Walley (1927) as *Callibaetis americanus* Banks, 1900; Neave (1929) as *Callibaetis coloradensis* Banks, 1900]. **BC** [Eaton (1885); McDunnough (1925a) as *Callibaetis coloradensis* Banks, 1900; McDunnough (1925a) as *Callibaetis tessellatus* (Hagen), 1861; Walley (1927) as *Callibaetis hageni* Eaton, 1885; Filmer (1964) as *Callibaetis carolus* Traver, 1935; Filmer (1964) as *Callibaetis nigritus* Banks, 1918]. **MB** [Banks (1912); McDunnough (1925a) as *Callibaetis americanus* Banks, 1900]. **NB** [McDunnough (1925a) as *Callibaetis coloradensis* Banks, 1900]. **NF** [Newfoundland Island: Check (1982)]. **NS** [Check (1982)]. **NW** [Cobb et al. (1995) as *Callibaetis coloradensis* Banks, 1900]. **ON** [Hagen (1861) misidentified as *Cloe bioculata* [sic] (Linnaeus), 1758; Banks (1900) as *Callibaetis americanus*

Banks, 1900, type; Clemens (1913)]. **PE** [adults, Queens Co., Rt. 1, Charlottetown, at light, 20 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1930) as *Callibaetis hageni* Eaton, 1885; Harper and Harper (1976)]. **SA** [adults, Sturgeon River at Hwy 240, 4 August 1969, D.M. Lehmkuhl (SASK); Rystrom's Pond, 4 km SE Saskatoon, 11 August 1986, Dale Parker (SASK); La Ronge, 9 August 1970, R.G. Holmberg (SASK); Twin Forks, 24 May 1974, R. Demaray (SASK)]. **YU** [Harper and Harper (1981) as *Callibaetis* prob. *coloradensis* Banks, 1900; Harper and Harper (1997)].

Callibaetis fluctuans (Walsh), 1862: **MB** [Hagen (1863) as *Cloe*]. **ON** [Walley (1927)]. **PQ** [Gibbs (1979)].

Callibaetis pallidus Banks, 1900: **AB** [Neave (1929)]. **MB** [Banks (1914) as *Callibaetis semicostatus* Banks, 1914, type; McDunnough (1925a)]. **NF** [Newfoundland Island: Berner (1959) as *Callibaetis* nr *skokianus* Needham, 1903]. **SA** [McDunnough (1925a)].

Callibaetis pretiosus Banks, 1924: **ON** [Thew (1959)].

Callibaetis skokianus Needham, 1903: **ON** [Ide (1930)]. **PQ** [Harper and Harper (1982)]. **SA** [Thew (1959) as *Callibaetis brevicostatus* Daggy, 1945].

Camelobaetidius warreni (Traver and Edmunds), 1968: **SA** [McCafferty and Klubertanz (1994)].

Centroptilum album McDunnough, 1926: **BC** [Scudder (1975)]. **MB** [Lowen and Flannagan (1991). **NB** [Lowen and Flannagan (1991)]. **ON** [McDunnough (1926a), type]. **PQ** [McDunnough (1926a)].

Centroptilum bifurcatum McDunnough, 1924: **AB** [McDunnough (1924a), type]. **BC** [Scudder (1975)]. **MB** [Lowen and Flannagan (1991)]. **ON** [larvae, Algoma Co., Lake Superior, Batchawana Bay, north shore, 8 August 1994, P. Hudson (PERC)]. **SA** [larvae and adults: South Saskatchewan River, Lemsford Ferry, 3, 26 September 1970, 28 August 1971, 29 June 1971, D.M. Lehmkuhl (SASK); South Saskatchewan River at Saskatoon, 10 August 1970, D.M. Lehmkuhl (SASK); North Saskatchewan River, ferry 10 mi E of Prince Albert, D.H. Smith, 21 September 1972 (SASK); adults, South Saskatchewan River, Saskatoon, .25 mi upstream of Queen Elizabeth Power Station, 27 June 1976, (SASK); North Saskatchewan River at Hwy 5 (Border Bridge), 18 June 1976, P.G. Mason (SASK)].

Centroptilum conturbatum McDunnough, 1929: **AB** [McDunnough (1929), type]. **BC** [Scudder (1975)]. **MB** [Flannagan et al. (1990)].

Centroptilum minor (McDunnough), 1926: **ON** [McDunnough (1926a) as *Cloeon*, type].

Centroptilum semirufum McDunnough, 1926: **ON** [Eaton (1871) misidentified as *Centroptilum luteolum* (Müller), 1776; McDunnough (1926a), type]. **PQ** [Dulude (1992)].

Centroptilum triangulifer (McDunnough), 1931: **ON** [McDunnough (1931a) as *Cloeon*, type]. **PQ** [McDunnough (1931a) as *Cloeon*].

Centroptilum victoriae McDunnough, 1938: **MB** [Lowen and Flannagan (1991)]. **NS** [McDunnough (1938), type]. **ON** [Lowen and Flannagan (1991)]. **SA** [larvae, North Saskatchewan R, Cecil Ferry 10 mi E Prince Albert, 11 June 1971, D.M. Lehmkuhl (SASK); adult, South Saskatchewan R, Lemsford Ferry, 12 July 1972, D.M. Lehmkuhl (SASK)].

Diphetor hageni (Eaton), 1885: **AB** [McDunnough (1925a, 1925b) as *Baetis parvus* Dodds, 1923; Morihara and McCafferty (1979) as *Baetis*]. **BC** [Walley (1927) as *Baetis parvus* Dodds, 1923]. **MB** [Gyselman (1980) as *Baetis*]. **NB** [Eidt (1975) as *Baetis herodes* Burks, 1953]. **NS** [adult and larvae, Cochester Co., Bailey's Brook, Rt 256, W of Falls, 3 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NW** [Cobb and Flannagan (1980) as *Baetis*]. **ON** [McDunnough (1925b) as *Baetis parvus* Dodds, 1923; Spence and Hynes (1971) as *Baetis* *herodes* Burks, 1953; Morihara and McCafferty (1979) as *Baetis*]. **PQ** [Walley (1927) as *Baetis parvus* Dodds, 1923; Morihara and McCafferty (1979) as *Baetis*]. **SA** [larvae, Pine Creek at Hwy 69, 17 June 1971, D.H. Smith (SASK)].

Fallceon quilleri (Dodds), 1923: **MB** [Flannagan et al. (1990) as *Baetis*]. **SA** [Lehmkuhl (1976a) as *Baetis*].

Heterocloeon curiosum (McDunnough), 1923: **NB** [Petersen (1989)]. **ON** [McDunnough (1923) as *Centroptilum*, type]. **PQ** [McDunnough (1925a)].

Heterocloeon frivolum (McDunnough), 1925: **ON** [McDunnough (1925d) as *Baetis*]. **PQ** [McDunnough (1925d) as *Baetis*, type].

Labiobaetis dardanus (McDunnough), 1923: **MB** [McDunnough (1923) as *Baetis*, type]. **ON** [McDunnough (1925a)]. **PQ** [McDunnough (1925a)]. **SA** [larvae, South Saskatchewan River, Lemsford Ferry, 21 June, 12 July 1971, D.M. Lehmkuhl, 25 June 1972, D.H. Smith (SASK); South Saskatchewan River, Saskatoon, .25 mi upstream from Queen Elizabeth Power Station, 23 July 1972, D.H. Smith (SASK); South Saskatchewan River, Clarksboro Ferry, 17 August 1972, D.H. Smith (SASK); South Saskatchewan River at Cecil Ferry, 11 June 1971, D.M. Lehmkuhl (SASK); South Saskatchewan River, 1 mi upstream from Saskatoon, 13 July 1971, D.M. Lehmkuhl (SASK); Saskatchewan River, Fronlid Ferry, 21 July 1971, D.H. Smith (SASK); North Saskatchewan River, at Hwy 5 (Borden Bridge), 31 July 1972, D.H. Smith (SASK); North Saskatchewan River, ferry S of Maymont, 6 June 1972, D.H. Smith (SASK); North Saskatchewan River, at Cecil Ferry, 11 June 1971, D.M. Lehmkuhl (SASK); North Saskatchewan River, 20 mi N of Lloydmenster, 4 July 1970, D.M. Lehmkuhl (SASK); adults, Saskatchewan River SW of Nipawin, 2 August 1972, D.H. Smith (SASK)].

Labiobaetis frondalis (McDunnough), 1925: **NS** [Morihara and McCafferty (1979) as *Baetis*]. **ON** [Walley (1927) as *Baetis*]. **PQ** [McDunnough (1925d) as *Baetis*, type].

Labiobaetis longipalpus (Morihara and McCafferty), 1979: **ON** [Griffiths (1996)].

Labiobaetis propinquus (Walsh), 1863: **MB** [McDunnough (1925d) as *Baetis spinosus* McDunnough, 1925, type]. **NB** [larvae, Kent Co., South Fork Coal Branch River, Hwy 126, 12 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Morihara and McCafferty (1979) as *Baetis*]. **ON** [Clemens (1913) as *Baetis*; Walley (1927) as *Baetis spinosus* McDunnough, 1925]. **PQ** [Walley (1927) as *Baetis spinosus* McDunnough, 1925; Harper and Harper (1981) as *Baetis*]. **SA** [adults, Sturgeon River at Hwy 240, 4 August 1969, D.M. Lehmkuhl (SASK); larvae, Little Red River Park, at Prince Albert, 17 June 1971, D.H. Smith (SASK); Saskatchewan River, ferry N of Fronlid, 29 July 1972, D.H. Smith (SASK)]. **YU** [Wiens et al. (1975) as *Baetis* cf. *propinquus*; Cobb and Flannagan (1980) as *Baetis*].

Plauditus armillatus McCafferty & Waltz, 1990: **AB** [McDunnough (1932b) as *Pseudocloeon parvulum* McDunnough, 1932]. **MB** [Flannagan and Flannagan (1982) as *Baetis parvulum* (McDunnough), 1932]. **ON** [McDunnough (1932b) as *Pseudocloeon parvulum* McDunnough, 1932, type of *P. armillatus*; Griffiths (1996) as *Baetis*]. **PQ** [McDunnough (1932b) as *Pseudocloeon parvulum* McDunnough, 1932]. **SA** [larvae and adults, South Saskatchewan River, ferry N of Birch Hills, 19 June 1974, D.H. Smith and L. Dodge (SASK)].

Plauditus cestus (Provonsha and McCafferty), 1982: **ON** [larvae, Nottawasaga River at Simcoe Side Road 10, 16 June 1997, R.W. Griffiths and C. Jones (PERC, RWG)].

Plauditus cinctutus McCafferty and Waltz, 1990: **ON** [Sprules (1947) as *Pseudocloeon cingulatum* McDunnough, 1931; Griffiths (1996) as *Baetis*]. **PQ** [McDunnough (1931a) as *Pseudocloeon cingulatum* McDunnough, 1931, type of *P. cinctutus*].

Plauditus dubius (Walsh), 1862: **AB** [McDunnough (1931a) as *Pseudocloeon*]. **MB** [McDunnough (1925a) as *Pseudocloeon*]. **ON** [McDunnough (1923) as *Cloeon chlorops* McDunnough, 1923, type; Ide (1937) as *Pseudocloeon dubium* (McDunnough)]. **PQ** [Walley (1927) as *Pseudocloeon chlorops* McDunnough, 1923]. **SA** [adults, South Saskatchewan River, ferry N of Birch Hills, 6 July 1972 (SASK)].

Plauditus futilis (McDunnough), 1931: **AB** [McDunnough (1931a) as *Pseudocloeon*, type].

Plauditus punctiventris (McDunnough), 1923: **MB** [Friesen et al. (1980) as *Pseudocloeon*; Gyselman (1980) as *Pseudocloeon myrsum* Burks, 1953]. **NB** [Petersen (1989) as *Pseudocloeon*]. **NS** [Petersen et al. (1987) as *Pseudocloeon*]. **ON** [McDunnough (1923) as *Cloeon*, type]. **PQ** [McDunnough (1925a) as *Pseudocloeon*]. **SA** [larvae, Battle River, S of Laburn, 27 August 1972, D.H. Smith (SASK)].

Plauditus rubrolateralis (McDunnough), 1931: **AB** [McDunnough (1931a) as *Pseudocloeon*, type].

Plauditus virilis (McDunnough), 1923: **ON** [McDunnough (1923) as *Cloeon*, type]. **PQ** [McDunnough (1924a) as *Pseudocloeon*]. **SA** [larvae, river 2 mi S Hudson Bay, Sask., 27 August 1969, D.M. Lehmkuhl (SASK)].

Procloeon bellum (McDunnough), 1924: **BC** [Filmer (1964) as *Centroptilum*]. **NB** [larvae, Charlo River, 2 August 1950, G.F. Edmunds (PERC)]. **NS** [Whiting (1992) misidentified as *Centroptilum venosum* Traver, 1935]. **ON** [Walley (1927) as *Centroptilum*]. **PQ** [McDunnough (1924a) as *Centroptilum*, type; Harper (1989) misidentified as *Centroptilum venosum* Traver, 1935].

Procloeon caliginosum (McDunnough), 1925: **PQ** [McDunnough (1925d) as *Centroptilum*, type].

Procloeon convexum (Ide), 1930: **MB** [Flannagan et al. (1990) as *Centroptilum*]. **NF** [Newfoundland Island: Larson and Colbo (1983) as *Centroptilum*]. **ON** [Ide (1930) as *Centroptilum*, type].

Procloeon fragile (McDunnough), 1923: **ON** [McDunnough (1923) as *Centroptilum*, type]. **PQ** [McDunnough (1925a) as *Centroptilum*].

Procloeon implicatum (McDunnough), 1924: **AB** [McDunnough (1923) misidentified in part as *Centroptilum ingens* McDunnough, 1923; McDunnough (1924a) as *Cloeon*, type]. **BC** [McDunnough (1924a) as *Cloeon*].

Procloeon inanum (McDunnough), 1924: **AB** [McDunnough (1924a) as *Cloeon*, type]. **MB** [Harper and Harper (1981) as *Cloeon*].

Procloeon ingens (McDunnough), 1923: **AB** [McDunnough (1923) as *Cloeon*, type]. **MB** [McDunnough (1925a) as *Cloeon*]. **PQ** [McDunnough (1930) as *Cloeon*]. **YU** [Harper and Harper (1997)].

Procloeon insignificans (McDunnough), 1925: **ON** [McDunnough (1925d) as *Cloeon*, type].

Procloeon intermediale (McDunnough), 1931: **PQ** [McDunnough (1931a) as *Centroptilum*, type].

Procloeon irrubrum Lowen and Flannagan, 1992: **MB** [Lowen and Flannagan (1992), type].

Procloeon mendax (Walsh), 1862: **ON** [Ide (1930) as *Cloeon*].

Procloeon ozburni (McDunnough), 1924: **ON** [McDunnough (1925a)]. **PQ** [McDunnough (1924a) as *Centroptilum*, type].

Procloeon pennulatum (Eaton), 1870: **AB** [McDunnough (1931a) as *Centroptilum infrequens* McDunnough, 1924]. **MB** [McDunnough (1924a) as *Centroptilum infrequens* McDunnough, 1924, type]. **NB** [larvae, Mirimichi River, 2 September 1950, E.L. Bousefield (PERC)].

NW [Lowen and Flannagan (1990) as *Centroptilum infrequens* McDunnough, 1924; Cobb et al. (1995)]. **SA** [Lowen and Flannagan (1990) as *Centroptilum infrequens* McDunnough, 1924].

Procloeon quaesitum (McDunnough), 1931: **AB** [McDunnough (1931a) as *Centroptilum*, type]. **MB** [Neave (1934) as *Centroptilum*]. **SA** [larvae, Wallaston Lake, Stm. 64, 6 July 1972 (SASK)].

Procloeon rivulare (Traver), 1935: **NS** [larvae, Riv. Philp, 9 July 1950, G.F. Edmunds (PERC); larvae, Hilisburn Stream, Rapids, 24 June 1950, G.F. Edmunds (PERC)].

Procloeon rubropictum (McDunnough), 1923: **MB** [Friesen et al. (1980) as *Cloeon*]. **NB** [larvae, Mirimichi River, 17 August 1950, E.L. Bousefield (PERC)]. **NS** [Whiting (1992)]. **ON** [Clemens (1913) as *Cloeon dubium* (Walsh), 1862; McDunnough (1923) as *Cloeon*, type]. **PQ** [McDunnough (1925a) as *Cloeon*]. **SA** [larvae, Lac La Ronge, Nemeiben River, 22 July 1969, D.M. Lehmkuhl (SASK)].

Procloeon rufostrigatum (McDunnough), 1924: **MB** [McDunnough (1924a) as *Centroptilum*, type]. **NB** [Traver (1935a) as *Centroptilum*]. **NS** [Whiting (1992)]. **PQ** [Harper and Harper (1981) as *Centroptilum*].

Procloeon simile (McDunnough), 1924: **ON** [Traver (1935a) as *Centroptilum*]. **PQ** [McDunnough (1924a) as *Centroptilum*, type].

Procloeon simplex (McDunnough), 1925: **ON** [Walley (1927) as *Cloeon*]. **PQ** [McDunnough (1925d) as *Cloeon*, type].

Procloeon viridoculare (Berner), 1940: **ON** [larvae, Nottawasaga River at Simcoe Side Road 10, 16 June 1997, R.W. Griffiths (RWG)].

Procloeon walshi (McDunnough), 1929: **MB** [Flannagan et al. (1990) as *Centroptilum*].

BAETISCIDAE

Baetisca callosa Traver, 1931 nomen dubium: **PQ** [McDunnough (1932b)].

Baetisca carolina Traver, 1931: **PQ** [McDunnough (1932b)].

Baetisca lacustris McDunnough, 1932: **AB** [Lehmkuhl (1972) as *Baetisca bajkovi* Neave, 1934; Pescador and Berner (1981)]. **MB** [McDunnough (1932b); Neave (1934) as *Baetisca bajkovi* Neave, 1934, type]. **ON** [Banks (1912) as *Baetisca obesa* (Say), 1839; McDunnough (1932b), type]. **PQ** [Dulude (1992)]. **SA** [Lehmkuhl (1972) as *Baetisca bajkovi* Neave, 1934; Pescador and Berner (1981)].

Baetisca laurentina McDunnough, 1932: **AB** [Pescador and Berner (1981)]. **MB** [Pescador and Berner (1981)]. **NB** [McDunnough (1932b)]. **NF** [Labrador: larvae, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); larvae, Ashuanipi River, Hwy 500, W of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); larva, Raft River, Hwy 500, 34 mi N of Churchhill Falls, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Whiting (1992)]. **NW** [Pescador and Berner (1981)]. **ON** [McDunnough (1932b)]. **PQ** [McDunnough (1932b), type].

Baetisca obesa (Say), 1839: **AB** [Lehmkuhl (1972)]. **MB** [Burks (1953)]. **NW** [Wiens et al. (1975) as *Baetisca* sp.; Cobb and Flannagan (1980)]. **ON** [Barton and Hynes (1978) and possibly earlier by Rawson (1930)]. **SA** [Lehmkuhl (1972)].

Baetisca rubescens (Provancher), 1878: **NF** [Labrador: larvae, West Metchin River, Hwy 500, 32 mi E of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); larvae, Unknown River, Twin Falls rd, 21 mi W of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [Provancher (1876) misidentified as *Cloe unicolor* Hagen, 1861; Provancher (1878) as *Cloe*, type].

CAENIDAE

Brachycercus flavus Traver, 1935: **PQ** [Harper and Harper (1976); Dulude (1992) misidentified as *Brachycercus prudens* (McDunnough), 1931].

Brachycercus lacustris (Needham), 1918: **NS** [larva, Hants Co., Herbert River, Hwy 4, 20 June 1994, R. Raymond (CSU)]. **ON** [Ide (1930) as *Eurycaenis pallidus* Ide, 1930, type]. **PQ** [Lauzon and Harper (1988)].

Brachycercus prudens (McDunnough), 1931: **SA** [McDunnough (1931e) as *Eurycaenis*, type].

Caenis amica Hagen, 1861: **AB** [McDunnough (1931e) as *Caenis simulans* McDunnough, 1931; Provonsha (1990)]. **BC** [Traver (1935a) as *Caenis simulans* McDunnough, 1931; Provonsha (1990)]. **MB** [McDunnough (1931e) as *Caenis simulans* McDunnough, 1931]. **NB** [McDunnough (1931e) as *Caenis simulans* McDunnough, 1931]. **NF** [Newfoundland Island: Larson and Colbo (1983) as *Caenis simulans* McDunnough, 1931]. **ON** [McDunnough (1931e) as *Caenis simulans* McDunnough, 1931, type]. **PQ** [McDunnough (1931e) as *Caenis simulans* McDunnough, 1931; Provonsha (1990)]. **SA** [McDunnough (1931e) as *Caenis simulans* McDunnough, 1931; Provonsha (1990)].

Caenis candida Harper and Harper, 1981: **PQ** [Harper and Harper (1981), type].

Caenis diminuta Walker, 1853: **NS** [Provonsha (1990)]. **ON** [Banks (1912)]. **PQ** [McDunnough (1925a)].

Caenis hilaris (Say), 1839: **ON** [Walley (1927)].

Caenis latipennis Banks, 1907: **AB** [Provonsha (1990)]. **MB** [McDunnough (1931e) as *Caenis forcipata* McDunnough, 1931; Provonsha (1990)]. **NB** [McDunnough (1931e) as *Caenis jocosa* McDunnough, 1931; Provonsha (1990)]. **ON** [McDunnough (1931e); McDunnough (1931e) as *Caenis forcipata* McDunnough, 1931, type; McDunnough (1931e) as *Caenis jocosa* McDunnough, 1931]. **PQ** [McDunnough (1931e) as *Caenis forcipata* McDunnough, 1931; McDunnough (1931e) as *Caenis jocosa* McDunnough, 1931; Provonsha (1990)]. **SA** [McDunnough (1931e)].

Caenis punctata McDunnough, 1931: **ON** [McDunnough (1931e)]. **PQ** [McDunnough (1931e), type].

Caenis tardata McDunnough, 1931: **AB** [McDunnough (1931e), type]. **MB** [Friesen et al. (1980)]. **SA** [McDunnough (1931e)].

Caenis youngi Roemhild, 1984: **AB** [Provonsha (1990)]. **NW** [Cobb et al. (1995)]. **ON** [all larvae: Young-Davidson Pond #1, Matachewan, 28 May 1996, R.W. Griffiths and G. Watson (PERC, RWG); small lakes nr Falconbridge, October 1997, D. Zaranko (PERC)]. **SA** [Parker (1992)]. **YU** [Cobb et al. (1995)].

EPHEMERELLIDAE

Attenella attenuata (McDunnough), 1925: **NB** [Allen and Edmunds (1961b) as *Ephemerella*]. **NS** [Petersen (1989) as *Ephemerella*]. **ON** [McDunnough (1931c) as *Ephemerella*]. **PQ** [McDunnough (1925c) as *Ephemerella*, type].

Attenella margarita (Needham), 1927: **AB** [Walley (1930) as *Ephemerella*]. **BC** [Walley (1927) misidentified as *Ephemerella attenuata* McDunnough, 1925; larvae, Trout Creek at Summerland, 16 August 1964, G.F. Edmunds (PERC)]. **NB** [Allen and Edmunds (1961b)]. **NS** [Allen and Edmunds (1961b)].

Caudatella heterocaudata (McDunnough), 1929: **BC** [McDunnough (1935) as *Ephemerella* *columbiella* McDunnough, 1935, type; Allen and Edmunds (1961a) as *Ephemerella*].

Caudatella hystrix (Traver), 1934: **BC** [McDunnough (1935) as *Ephemerella*].

Caudatella jacobi (McDunnough), 1939: **BC** [McDunnough (1939) as *Ephemerella*, type].

Drunella coloradensis (Dodds), 1923: **AB** [McDunnough (1929) as *Ephemerella*]. **BC** [Clemens et al. (1938) as *Ephemerella*; Mayo (1952) as *Ephemerella wilsoni* Mayo, 1952, type]. **NW** [Cobb et al. (1995)]. **YU** [Allen and Edmunds (1962b)].

Drunella cornuta (Morgan), 1911: **NB** [Petersen (1989) as *Ephemerella*]. **NF** [Newfoundland Island: Berner (1959) misidentified as *Ephemerella cornutella* McDunnough, 1931]. **NS** [Allen and Edmunds (1962b)]. **ON** [Ide (1930) as *Ephemerella depressa* Ide, 1930, type; Allen and Edmunds (1962b) as *Ephemerella*]. **PQ** [McDunnough (1931c) as *Ephemerella*].

Drunella cornutella (McDunnough), 1931: **NB** [McDunnough (1931c) as *Ephemerella*]. **NF** [Labrador: larvae, Miron River, Hwy 500, E of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [McDunnough (1931c) as *Ephemerella*]. **PQ** [McDunnough (1931a) as *Ephemerella*, type; McDunnough (1931c) as *Ephemerella*].

Drunella doddsi (Needham), 1927: **AB** [McDunnough (1928a) as *Ephemerella*]. **BC** [Clemens et al. (1938) as *Ephemerella*]. **NW** [Cobb et al. (1995)]. **YU** Allen and Edmunds (1962b) as *Ephemerella*].

Drunella flavilinea (McDunnough), 1926: **AB** [McDunnough (1926a) as *Ephemerella*, type; Hartland-Rowe (1964) as *Ephemerella lapidula* McDunnough, 1935]. **BC** [Walley (1927) as *Ephemerella*].

Drunella grandis (Eaton), 1884: **AB** [Neave (1929)]. **BC** [McDunnough (1934) as *Ephemerella ingens* McDunnough, 1934, type; Allen and Edmunds (1962b) as *Ephemerella*]. **SA** [Lehmkuhl (1976a) as *Ephemerella*]. **YU** [Allen and Edmunds (1962b)].

Drunella lata (Morgan), 1911: **NB** [Allen and Edmunds (1962b) as *Ephemerella*]. **NS** [Allen and Edmunds (1962b) as *Ephemerella*]. **PQ** [McDunnough (1926a) as *Ephemerella inflata* McDunnough , 1926, type; McDunnough (1931c) as *Ephemerella*].

Drunella pelosa (Mayo), 1951: **BC** [Scudder (1975) as *Ephemerella*].

Drunella spinifera (Needham), 1927: **AB** [Barton (1980) as *Ephemerella*]. **BC** [McDunnough (1934) as *Ephemerella autumnalis* McDunnough, 1934, type; Mayo (1952) as *Ephemerella*].

Drunella tuberculata (Morgan), 1911: **NB** [Petersen and Martin-Robichaud (1986)]. **NS** [Petersen et al. (1985)]. **ON** [McDunnough (1931c) as *Ephemerella*]. **PQ** [McDunnough (1931c) as *Ephemerella*].

Drunella walkeri (Eaton), 1884: **NB** [McDunnough (1931c) as *Ephemerella fuscata* (Walker), 1853; Allen and Edmunds (1962b) as *Ephemerella*]. **NS** [Allen and Edmunds (1962b) as *Ephemerella*]. **ON** [Walker (1853) as *Baetis fuscata* Walker, 1853, type of *D. walkeri*]. **PQ** [McDunnough (1925a) as *Ephemerella fuscata* (Walker), 1853; McDunnough (1931c) as *Ephemerella*].

Ephemerella aurivillii (Bengtsson), 1908: **AB** [McDunnough (1924b) as *Ephemerella norda* McDunnough, 1924, type; Barton (1980)]. **BC** [Wigle and Thommasen (1990)]. **NB** [Eidt (1975)]. **NF** [Newfoundland Island: Berner (1959). Labrador: larva, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); larvae, Trout River, Hwy 510 N of Pinware, 6 June 1998, B.C. Kondratieff and R.W. Baumann (CSU, PERC)]. **NS** [Petersen (1989)]. **NW** [Moore (1977)]. **ON** [Ide (1930) as *Ephemerella aronii* Eaton, 1908; Ide (1935b)]. **PE** [adult, Queens Co., Northeast Margaree River, above Intervale, 19 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1930) as *Ephemerella aronii* Esben-Petersen [sic]; Walley (1930) as *Ephemerella aronii* Eaton, 1908;

McDunnough (1932a)]. **SA** [Lehmkuhl (1976a)].

Ephemerella dorothea Needham, 1908: **NB** [McDunnough (1931c)]. **NS** [Allen and Edmunds (1965)]. **PE** [larvae, Queens Co., Dunk River, Hwy 232, 29 June 1994, C. Goforth (CSU)]. **PQ** [McDunnough (1925a, 1925b)].

Ephemerella excrucians Walsh, 1862: **NB** [McDunnough (1931a)]. **NS** [Petersen et al. (1985)]. **NW** [Wiens et al. (1975) as *Ephemerella excrucians*?; Cobb and Flannagan (1980)]. **ON** [McDunnough (1925a, 1925d); McDunnough (1926b) as *Ephemerella semiflava* McDunnough, 1926, type]. **PQ** [McDunnough (1931c)].

Ephemerella fratercula McDunnough, 1925: **PQ** [McDunnough (1925b), type].

Ephemerella inermis Eaton, 1884 **AB** [McDunnough (1925a)]. **BC** [McDunnough (1925a)]. **NW** [Cobb et al. 1995)]. **SA** [Lehmkuhl (1976a)].

Ephemerella infrequens McDunnough, 1924: **AB** [McDunnough (1924b), type]. **BC** [Walley (1927)].

Ephemerella invaria (Walker), 1853: **MB** [Flannagan and Flannagan (1982)]. **NB** [Allen and Edmunds (1965)]. **NF** [Newfoundland Island: tributary to Salon River, E of Ten Mile Lake, Hwy 432, 8 June 1998, B.C. Kondratieff and R.W. Baumann (CSU, PERC). Labrador: larvae, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, Ashuanipi River, Hwy 500, W of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adults, Raft River, Hwy 500, 34 mi N of Churchhill Falls, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); larvae, West Metchin River, Hwy 500, 32 mi E of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adults, Unknown River, Twin Falls rd. 21 mi W of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Allen and Edmunds (1965)]. **NW** [Wiens et al. (1975)]. **ON** [Walker (1853) as *Baetis*, type]. **PE** [Allen and Edmunds 1965)]. **PQ** [McDunnough (1925a, 1925b)].

Ephemerella mucronata (Bengtsson), 1909: **NW** [Harper and Harper (1981)]. **YU** [Harper and Harper (1981)].

Ephemerella needhami McDunnough, 1925: **NB** [Allen and Edmunds (1965)]. **NS** [Allen and Edmunds (1965)]. **ON** [Walley (1927)]. **PQ** [McDunnough (1925d), type].

Ephemerella quebecensis (Provancher), 1876 nomen dubium: **PQ** [Provancher (1876) as *Cloe*, type].

Ephemerella rotunda Morgan, 1911: **NB** [Eidt (1975)]. **NS** [Allen and Edmunds (1965)]. **ON** [McDunnough (1926a)]. **PQ** [McDunnough (1931c)].

Ephemerella septentrionalis McDunnough, 1925: **NB** [Allen and Edmunds (1965)]. **ON** [McDunnough (1925d), type]. **PQ** [McDunnough (1931c)].

Ephemerella subvaria McDunnough, 1931: **NB** [Petersen (1989)]. **NF** [Newfoundland Island: Larson and Colbo (1983). Labrador: larva, Miron River, Hwy 500, E of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Petersen (1989)]. **ON** [Ide (1930) misidentified as *Ephemerella invaria* (Walker), 1853; McDunnough (1931a, 1931c)]. **PQ** [McDunnough (1925a, 1925b) misidentified as *Ephemerella invaria* (Walker), 1853; McDunnough (1931a), type; McDunnough (1931c)].

Eurylophella aestiva (McDunnough), 1931: **NB** [Eidt (1975) as *Ephemerella*]. **NS** [Petersen et al. (1985) as *Ephemerella*]. **ON** [Allen and Edmunds (1963b) as *Ephemerella*]. **PQ** [McDunnough (1931b) as *Ephemerella*, type].

Eurylophella bartoni (Allen), 1977: **ON** [Allen (1977) as *Ephemerella*, type].

Eurylophella bicolor (Clemens), 1913: **MB** [Neave (1934) as *Ephemerella*]. **NB** [McDunnough (1931b) as *Ephemerella*]. **NS** [Allen and Edmunds (1963b) as *Ephemerella*]. **NW** [Cobb and

Flannagan (1980)]. **ON** [Clemens (1913) as *Ephemerella*, type]. **PQ** [McDunnough (1925a) as *Ephemerella*].

Eurylophella bicoloroides (McDunnough), 1938: **NS** [McDunnough (1938) as *Ephemerella*, type].

Eurylophella coxalis (McDunnough), 1926: **NS** [Allen and Edmunds (1963b) as *Ephemerella*]. **ON** [Walley (1927) as *Ephemerella*]. **PQ** [McDunnough (1926a) as *Ephemerella*, type].

Eurylophella enoensis Funk, 1994: **ON** [Funk and Sweeney (1994)].

Eurylophella funeralis (McDunnough), 1925: **NB** [Allen and Edmunds (1963b) as *Ephemerella*]. **NF** [Newfoundland Island: Larson and Colbo (1983)]. **NS** [Allen and Edmunds (1963b) as *Ephemerella*]. **ON** [Walley (1927) as *Ephemerella*]. **PQ** [McDunnough (1925b) as *Ephemerella*, type].

Eurylophella lodi (Mayo), 1952: **BC** [Allen and Edmunds (1963b) as *Ephemerella*].

Eurylophella lutulenta (Clemens), 1913: **NB** [McDunnough (1931b) as *Ephemerella*]. **ON** [Clemens (1913) as *Ephemerella lineata* Clemens, 1913, type; Clemens (1913) as *Ephemerella*, type]. **PQ** [McDunnough (1925a) as *Ephemerella*].

Eurylophella minimella (McDunnough), 1931: **NB** [Allen and Edmunds (1963b) as *Ephemerella*]. **NS** [Allen and Edmunds (1963b) as *Ephemerella*]. **ON** [Allen and Edmunds (1963b) as *Ephemerella*]. **PQ** [McDunnough (1931b) as *Ephemerella*, type].

Eurylophella prudentalis (McDunnough), 1931: **NB** [Allen and Edmunds (1963b) *Ephemerella*]. **NF** [Newfoundland Island: Berner (1959) as *Ephemerella*]. **NS** [Allen and Edmunds (1963b) as *Ephemerella*]. **ON** [McDunnough (1931b) as *Ephemerella*]. **PQ** [McDunnough (1931b) as *Ephemerella*, type].

Eurylophella temporalis (McDunnough), 1924: **MB** [Flannagan and Lawler (1972) as *Ephemerella*]. **NB** [McDunnough (1925a) as *Ephemerella*]. **NS** [Petersen et al. (1985) as *Ephemerella*]. **NW** [Funk and Sweeney (1994)]. **ON** [McDunnough (1924c), as *Ephemerella*, type]. **PQ** [McDunnough (1925a, 1925b) as *Ephemerella*]. **SA** [Allen and Edmunds (1963b) as *Ephemerella*].

Eurylophella verisimilis (McDunnough), 1930: **NB** [McDunnough (1931b) as *Ephemerella*]. **NS** [Allen and Edmunds (1963b) as *Ephemerella*]. **ON** [McDunnough (1931b) as *Ephemerella*]. **PQ** [McDunnough (1930) as *Ephemerella*, type].

Serratella deficiens (Morgan), 1911: **NB** [McDunnough (1931c) as *Ephemerella*]. **NF** [Labrador: larvae, Unknown River, Twin Falls rd. 21 mi W of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [McDunnough (1931c) as *Ephemerella*]. **ON** [McDunnough (1925c) as *Ephemerella atrescens* McDunnough, 1925, type; Ide (1930) as *Ephemerella*]. **PQ** [McDunnough (1925a, 1925b, 1925c) as *Ephemerella atrescens* McDunnough, 1925].

Serratella molita (McDunnough), 1930: **NB** [McDunnough (1931c) as *Ephemerella*]. **NS** [McDunnough (1930) as *Ephemerella*]. **PQ** [McDunnough (1930) as *Ephemerella*, type].

Serratella serrata (Morgan), 1911: **NB** [Allen and Edmunds (1963a) as *Ephemerella*]. **NS** [Petersen et al. (1985)]. **ON** [McDunnough (1925a) as *Ephemerella*]. **PQ** [McDunnough (1925a) as *Ephemerella*].

Serratella serratoides (McDunnough), 1931: **NB** [Allen and Edmunds (1963a) as *Ephemerella*]. **NS** [McDunnough (1931c) as *Ephemerella*]. **ON** [McDunnough (1931c) as *Ephemerella*]. **PQ** [McDunnough (1930) as *Ephemerella serrata* Morgan, 1911; McDunnough (1931a) as *Ephemerella*, type; McDunnough (1931c) as *Ephemerella*].

Serratella sordida (McDunnough), 1925: **ON** [Ide (1930) as *Ephemerella*]. **PQ** [McDunnough (1925c) as *Ephemerella*, type].

Serratella teresa (Traver), 1934: **BC** [Filmer (1964) as *Ephemerella*].

Serratella tibialis (McDunnough), 1924: **AB** [McDunnough (1924b) as *Ephemerella*, type]. **BC** [Clemens et al. (1939) as *Ephemerella*]. **NW** [Cobb et al. (1995)].

Timpanoga hecuba (Eaton), 1884: **AB** [McDunnough (1935) as *Ephemerella*]. **BC** [McDunnough (1935) as *Ephemerella*].

Timpanoga lita (Burks), 1949: **SA** [Lehmkuhl (1976a) as *Ephemerella*].

Timpanoga simplex (McDunnough), 1925: **AB** [Barton (1980) as *Ephemerella*]. **MB** [Allen and Edmunds (1962a) as *Ephemerella*]. **NB** [McDunnough (1931c) as *Ephemerella*]. **NS** [Petersen et al.(1985)]. **NW** [Cobb and Flannagan (1980) as *Ephemerella*]. **ON** [Walley (1927) as *Ephemerella*]. **PQ** [McDunnough (1925c) as *Ephemerella*, type]. **SA** [Lehmkuhl (1976a) as *Ephemerella*].

EPHEMERIDAE

Ephemera guttulata Pictet, 1843: **NB** [adults, Magaguadavic River, Hwy 3, Brockway, 30 June 1995, S. Schuler (CSU)]. **NF** [Labrador: male subimago, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [adults, Hants Co., Herbert River, Hwy 4, 20 June 1994, R. Raymond (CSU)]. **ON** [McDunnough (1925)]. **PQ** [Provancher (1876) misidentified as *Ephemera simulans* Walker, 1853; Provancher (1878) as "Ephémère guttulée"].

Ephemera simulans Walker, 1853: **AB** [McDunnough (1925a)]. **BC** [McDunnough (1925a)]. **MB** [Banks (1912) as *Ephemera decora* Walker, 1853; Neave (1932)]. **NB** [adults, Charlotte Co., tributary of Digdequash River, Rt. 122, 15 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Whiting (1992)]. **NW** [Wiens et al. (1975)]. **ON** [Walker (1853) as *Palingenia natata* Walker, 1853, type; Banks (1910)]. **PQ** [Walker (1853), type]. **SA** [Hagen (1863) as *Ephemera natata* (Walker), 1853; Lehmkuhl (1976a)].

Ephemera varia Eaton, 1883: **NS** [adult, Hants Co., Herbert River, Hwy 4, 20 June 1994, R. Raymond (CSU)]. **ON** [Griffiths (1996)]. **PQ** [McDunnough (1925a, 1925b)].

Hexagenia atrocaudata McDunnough, 1924: **ON** [McDunnough (1924a), type].

Hexagenia bilineata (Say), 1824: **MB** [Hagen (1863) as *Palingenia*]. **ON** [Banks (1910)]. **PQ** [Provancher (1876) misidentified as *Palingenia limbata* (Serville), 1829; Provancher (1878) as *Palingenia*].

Hexagenia limbata (Serville), 1829: **AB** [Clifford (1969)]. **BC** [McDunnough (1925a)]. **MB** [Hagen (1861) as *Palingenia occulta* Walker, 1853; McDunnough (1925a)]. **NB** [Spieth (1941)]. **NW** [Harper and Harper (1981)]. **ON** [Walker (1853) as *Palingenia occulta* Walker, 1853, type; Walker (1853) as *Palingenia viridescens* Walker , 1853, type; Hagen (1861) as *Palingenia*; McDunnough (1927a) as *Hexagenia affiliata* McDunnough, 1927, type; Spieth (1941) as *Hexagenia munda* Eaton, 1883]. **PQ** [McDunnough (1925a); McDunnough (1927a) as *Hexagenia occulta* (Walker), 1853; Spieth (1941) as *Hexagenia munda* Eaton, 1883]. **SA** [Spieth (1941)].

Hexagenia rigida McDunnough, 1924: **MB** [McDunnough (1924a)]. **NB** [Spieth (1941)]. **NS** [adult, Hants Co., Herbert River, Hwy 4, 20 June 1994, R. Raymond (CSU)]. **ON** [McDunnough (1924a), type]. **PQ** [McDunnough (1924a)].

Litobrancha recurvata (Morgan), 1913: **NF** [Labrador: larvae, Route 530 S of Labrador City, overflow of Walsh River, 11 June 1997, B.C. Kondratieff and R.W. Baumann (PERC)]. **ON** [Spieth (1941) as *Hexagenia*]. **PQ** [Walley (1927) as *Hexagenia*].

Pentagenia vittigera (Walsh), 1862: **MB** [McDunnough (1925a)]. **ON** [Griffiths (1996) as unspecified species of *Pentagenia* from Thunder Bay)].

HEPTAGENIIDAE

Acanthomola pubescens Whiting & Lehmkuhl, 1987: **AB** [Whiting and Lehmkuhl (1987b)]. **SA** [Whiting and Lehmkuhl (1987b), type].

Anepeorus rusticus McDunnough, 1925: **SA** [McDunnough (1925d), type].
Anepeorus simplex (Walsh), 1963: **ON** [Griffiths (1996) as unspecified species of *Anepeorus*].

Cinygma integrum Eaton, 1885: **BC** [McDunnough (1926b)].
Cinygma lyriforme (McDunnough), 1924: **AB** [McDunnough (1924b) as *Ecdyonurus*, type].

Cinygmula confusa (McDunnough), 1924: **AB** [McDunnough (1924a) as *Cinygma*, type].
Cinygmula gartrelli McDunnough, 1934: **BC** [McDunnough (1934), type].
Cinygmula kootenai McDunnough, 1943: **BC** [McDunnough (1943), type].
Cinygmula mimus (Eaton), 1885: **AB** [McDunnough (1924a) as *Cinygma*]. **BC** [Walley (1927) as *Cinygma*]. **SA** [Whiting and Sheard (1990)]. **YU** [Harper and Harper (1997)].
Cinygmula par (Eaton), 1885: **AB** [McDunnough (1924a) as *Cinygma hyalina* McDunnough, 1924, type]. **BC** [Walley (1927) as *Cinygma hyalina* McDunnough, 1924; Scudder (1975)]. **YU** [Harper and Harper (1997)].
Cinygmula ramaleyi (Dodds), 1923: **AB** [McDunnough (1924a) as *Cinygma*; Neave (1929) as *Iron tollandi* Dodds, 1923]. **BC** [Walley (1927) as *Cinygma*]. **YU** [Harper and Harper (1997)].
Cinygmula subaequalis (Banks), 1914: **NB** [Whiting (1992)]. **NS** [McDunnough (1924a) as *Cinygma atlantica* McDunnough, 1924, type; Whiting (1992)]. **PE** [adults, Queens Co., Dund River, Hwy 232, 29 June 1994, C. Goforth (CSU)]. **PQ** [Dulude (1992)].
Cinygmula tarda (McDunnough), 1929: **AB** [McDunnough (1929) as *Cinygma*, type]. **NW** [Cobb and Flannagan (1980) as *Cinygmula* cf. *tarda*].
Cinygmula uniformis McDunnough, 1934: **BC** [McDunnough (1934), type]. **YU** [adults, Yukon – Alaska Hwy M P 632, 28 June 1952 (PERC)].

Epeorus albertae (McDunnough), 1924: **AB** [McDunnough (1924a) as *Iron*, type]. **BC** [Wigle and Thommasen (1990)]. **MB** [Flannagan et al. (1990)]. **ON** [larvae, North Madawaska River, Algonquin Park, 11 July 1955, B.V. Petersen (PERC)].
Epeorus deceptivus (McDunnough), 1924: **AB** [McDunnough (1924a) as *Cinygma*, type]. **BC** [McDunnough (1926b) as *Iron*]. **NW** [Moore (1977)].
Epeorus dulciana (McDunnough), 1935: **BC** [McDunnough (1935) as *Iron*, type].
Epeorus fragilis (Morgan), 1911: **NS** [McDunnough (1925a) as *Iron*]. **PQ** [McDunnough (1933a) as *Iron gracilis* [sic] Morgan, 1911; Dulude (1992) as *Iron*].
Epeorus grandis McDunnough, 1924: **AB** [McDunnough (1924a) as *Iron*, type]. **BC** [McDunnough (1925a) as *Iron*]. **NW** [Cobb et al. (1995)]. **YU** [Harper and Harper (1997)].
Epeorus longimanus (Eaton), 1885: **AB** [McDunnough (1924a) as *Iron*]. **BC** [McDunnough (1925a) as *Iron*]. **NW** [Cobb et al. (1995)]. **SA** [Lehmkuhl (1976a)]. **YU** [Harper and Harper (1997)].
Epeorus permagnus (Traver), 1935: **BC** [Filmer (1964)].
Epeorus pleuralis (Banks), 1910: **NB** [Walley (1927) as *Iron*]. **NF** [Newfoundland Island, Berner (1959) as *Epeorus* sp.; Dance (1979). Labrador: adults, stream entering Moosehead Lake, Hwy 500, E of Labrador City, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU);

adult, Ahuanipi River, Hwy 500, W of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adults, West Metchin River, Hwy 500, 32 mi E of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); larva, Trout Brook, Hwy 510 N of Pinware, 6 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Whiting (1992)]. **ON** [Ide (1930) as *Iron*]. **PE** [adult, Queens Co., Dunk River, Hwy 232, 18 June 1993, B.C. Kondratieff and R.W. Baumann (CSU); adult, Kings Co., Morell River, Hwy 320, 20 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1925a, 1925b) as *Iron*; Vincent (1985) as *Iron fraudator* Traver, 1935].

Epeorus punctatus (McDunnough), 1925: **ON** [McDunnough (1925d) as *Iron*, type]. **PQ** [McDunnough (1925d) as *Iron*].

Epeorus suffusus (McDunnough), 1925: **ON** [Walley (1927) as *Iron*]. **PQ** [McDunnough (1925d) as *Iron*, type].

Epeorus vitreus (Walker), 1853: **MB** [Friesen et al. (1980)]. **NB** [Petersen and Martin-Robichaud (1986)]. **NS** [Petersen (1989)]. **ON** [Walker (1853) as *Palingenia*, type; McDunnough (1924a) as *Iron humeralis* (Morgan), 1911]. **PQ** [McDunnough (1925a, 1925b, 1925d) as *Iron humeralis* (Morgan), 1911; Harper and Harper (1981)].

Heptagenia adaequata McDunnough, 1924: **AB** [McDunnough (1924a), type]. **SA** [McDunnough (1925a)].

Heptagenia diabasia Burks, 1946: **ON** [larvae, Madawaska River, Algonquin Park, 8 July 1966, R. and D. Koss (PERC)]. **PQ** [Koss (1970)]. **SA** [Whiting and Sheard (1990)].

Heptagenia elegantula (Eaton), 1885: **BC** [McDunnough (1925a)]. **MB** [McDunnough (1924a) as *Heptagenia querula* McDunnough, 1924, type; McDunnough (1925a)]. **SA** [Walley (1927)].

Heptagenia flavescens (Walsh), 1862: **BC** [Banks (1912)]. **MB** [McDunnough (1924a)]. **NW** [Wiens et al. (1975)]. **ON** [Barton and Hynes (1978)]. **SA** [Lehmkuhl (1976a)].

Heptagenia manifesta (Eaton), 1885 nomen dubium: **PQ** [Walley (1927)].

Heptagenia marginalis Banks, 1910: **ON** [McDunnough (1925a)]. **PQ** [McDunnough (1925a)].

Heptagenia pulla (Clemens), 1913: **MB** [Neave (1934)]. **NB** [adult, Miramichi, 3–5 May 1962, B.V. Petersen (PERC)]. **NF** [Newfoundland Island: Larson and Colbo (1983)]. **NS** [Whiting (1992)]. **NW** [Wiens et al. (1975); Moore (1977) as *Heptagenia julia* Traver, 1933]. **ON** [Clemens (1913) as *Ecdyonurus grandis* sp. nov. (nomen nudum); Clemens (1913) as *Ecdyurus*, type)]. **PQ** [McDunnough (1925a, 1925b)]. **SA** [Lehmkuhl (1976a)]. **YU** [Harper and Harper (1981)].

Heptagenia solitaria McDunnough, 1924: **AB** [McDunnough (1924a), type]. **BC** [McDunnough (1925a)]. **SA** [Lehmkuhl (1976a)].

Ironodes arctus Traver, 1935: **BC** [Edmunds et al. (1976) – no data].

Ironodes flavipennis Traver, 1935: **BC** [Traver (1935b), type]

Ironodes nitidus (Eaton), 1885: **BC** [Wigle and Thommasen (1990) as *Epeorus*].

Leucrocuta aphrodite (McDunnough), 1926: **MB** [Flannagan and Flannagan (1982) as *Heptagenia*]. **ON** [Walley (1927) as *Heptagenia*]. **PQ** [McDunnough (1926a) as *Heptagenia*, type].

Leucrocuta hebe (McDunnough), 1924: **MB** [McDunnough (1925a) as *Heptagenia*]. **NB** [Petersen (1989) as *Heptagenia*]. **NS** [Petersen (1989) as *Heptagenia*]. **NW** [Cobb and Flannagan (1980) as *Heptagenia*]. **ON** [McDunnough (1924a) as *Heptagenia*]. **PQ** [McDunnough (1924a) as *Heptagenia*, type]. **SA** [Lehmkuhl (1976a) as *Heptagenia*].

Leucrocuta jewetti (Allen), 1966: **MB** [Friesen et al. (1980) as *Heptagenia*].

Leucrocuta juno (McDunnough), 1924: **ON** [Barton and Hynes (1978) as *Heptagenia*]. **PQ** [McDunnough (1924a) as *Heptagenia*, type].
Leucrocuta maculipennis (Walsh) 1863: **MB** [McDunnough (1924a) as *Heptagenia*]. **NW** [Cobb and Flannagan (1980) as *Heptagenia*]. **ON** [Clemens (1913) as *Ecdyurus*].
Leucrocuta minerva (McDunnough), 1924: **ON** [McDunnough (1924a) as *Heptagenia*]. **PQ** [McDunnough (1924a) as *Heptagenia*, type].
Leucrocuta umbratica (McDunnough), 1931: **MB** [Flannagan and Flannagan (1982) as *Heptagenia*]. **PQ** [McDunnough (1931a) as *Heptagenia*, type].
Leucrocuta walshi (McDunnough), 1926: **ON** [McDunnough (1926a) as *Heptagenia*, type]. **PQ** [Dulude (1992)].

Macdunnoa nipawinia Lehmkuhl, 1979: **SA** [Lehmkuhl (1979), type].

Nixe criddlei (McDunnough), 1927: **AB** [McDunnough (1927b) as *Heptagenia*]
Nixe horrida (McDunnough), 1926: **ON** [McDunnough (1926b) as *Heptagenia*, type].
Nixe inconspicua (McDunnough), 1924: **MB** [McDunnough (1924a) as *Heptagenia*, type]. **ON** [Walley (1927)]. **PQ** [Walley (1927)]. **SA** [Whiting and Sheard (1990)].
Nixe lucidipennis (Clemens), 1913: **ON** [Clemens (1913) as *Ecdyurus*, type]. **PQ** [McDunnough (1925a) as *Heptagenia*]. **SA** [Whiting and Sheard (1990)].
Nixe perfida (McDunnough), 1926: **ON** [McDunnough (1926b) as *Heptagenia*, type].
Nixe rusticalis (McDunnough), 1931: **PQ** [McDunnough (1931a) as *Heptagenia*, type]. **SA** [Whiting and Sheard (1990)].
Nixe simplicioides (McDunnough), 1924: **AB** [McDunnough (1924a) as *Heptagenia*, type]. **BC** [Scudder (1975) as *Heptagenia*]. **MB** [Cobb et al. (1991)].

Raptoheptagenia cruentata (Walsh), 1863: **MB** [McDunnough (1924a) as *Heptagenia reversalis* McDunnough, 1924, type]. **SA** [Whiting and Lehmkuhl (1987a)].

Rhithrogena amica Traver, 1935: **PQ** [Dulude (1992)].
Rhithrogena anomala McDunnough, 1928: **PQ** [McDunnough (1928b), type].
Rhithrogena brunneotincta McDunnough, 1933: **PQ** [McDunnough (1933c), type].
Rhithrogena futilis McDunnough, 1934: **AB** [McDunnough (1926a) as *Rhithrogena doddsi* McDunnough, 1926, type; McDunnough (1934)]. **YU** [Harper and Harper (1981)].
Rhithrogena gaspeensis McDunnough, 1933 **PQ** [McDunnough (1933c), type].
Rhithrogena hageni Eaton, 1885: **AB** [McDunnough (1926a) as *Rhithrogena doddsi* McDunnough, 1926, type; McDunnough (1928a) as *Rhithrogena brunnea* Hagen, 1875]. **BC** [Scudder (1975)].
Rhithrogena impersonata (McDunnough), 1925: **NB** [Whiting (1992)]. **NS** [Whiting (1992)]. **ON** [Ide (1954); Ide (1954) as *Rhithrogena sanguinea* Ide, 1954, type]. **PQ** [McDunnough (1925d) as *Heptagenia*, type].
Rhithrogena jejuna Eaton, 1885: **AB** [McDunnough (1925a) as *Heptagenia*]. **BC** [Walley (1927)]. **NB** [Whiting (1992)]. **NF** [Labrador: Harper and Harper (1981)]. **NS** [Whiting (1992)]. **NW** [McDunnough (1925a) as *Heptagenia*]. **ON** [Walker (1853) as *Baetis fusca* Walker, 1853, type of *R. jejuna*]. **PQ** [Harper et al. (1975)]. **SA** [Walley (1927)].
Rhithrogena morrisoni (Banks), 1924: **AB** [McDunnough (1934)]. **BC** [Scudder (1975)].
Rhithrogena pellucida Daggy, 1945: **MB** [Friesen et al. (1980)]. **ON** [larvae, Missinaibi River, Station 6-1, 21 July 1996, R.W. Griffiths (PERC, RWG)].
Rhithrogena robusta Dodds, 1923: **AB** [McDunnough (1929)]. **BC** [Scudder (1975)].

Rhithrogena undulata (Banks), 1924: **NF** [Newfoundland Island: Dance (1979)]. **NW** [Wiens et al. (1975)]. **SA** [Whiting and Sheard (1990)]. **YU** [Harper and Harper (1997)].

Rhithrogena virilis McDunnough, 1934: **AB** [McDunnough (1928a) as *Rhithrogena brunnea* (Hagen), 1875; Clifford et al. (1973)]. **BC** [McDunnough (1934), type].

Stenacron candidum (Traver), 1935: **ON** [Flannagan and Cobb (1995)]. **PQ** [Dulude (1992)].

Stenacron carolina (Banks), 1914: **ON** [Sprules (1947)]. **PQ** [McDunnough (1925a, 1925b) as *Ecdyonurus*].

Stenacron gildersleevei (Traver), 1935: **MB** [adults, Winnipeg River, Hwy 44, 8 July 1979, G.F. Edmunds (PERC)].

Stenacron interpunctatum (Say), 1839: **AB** [Barton (1980); Hamilton and Clifford (1983) as *Stenacron canadensis* (Walker), 1853]. **MB** [Banks (1912) as *Heptagenia canadensis* (Walker), 1853; McDunnough (1925a) as *Ecdyonurus*]. **NB** [Lewis (1974) as *Stenonema*]. **NF** [Labrador: adults and larvae, Raft River, West of Churchhill Falls, Rt 5000, 2 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Petersen et al. (1987)]. **ON** [Say (1839) as *Baetis*, type; Walker (1853) as *Baetis canadensis* Walker, 1853, type; Clemens (1913) as *Heptagenia frontalis* Banks, 1910; McDunnough (1933a) as *Ecdyonurus heterotarsalis* McDunnough, 1933]. **PE** [larvae, Queens Co., Dunk River, Hwy 232, 29 June 1994, C. Goforth (CSU)]. **PQ** [Clemens and Leonard (1924) as *Heptagenia*; McDunnough (1925a) as *Ecdyonurus frontalis* (Banks), 1910; McDunnough (1925a, 1925b) as *Ecdyonurus canadensis* (Walker), 1853; McDunnough (1933a) as *Ecdyonurus heterotarsalis* McDunnough, 1933, type; Traver (1935a) as *Stenonema*]. **SA** [Lehmkuhl (1976a)].

Stenonema exiguum Traver, 1933: **ON** [Daggy (1945)].

Stenonema femoratum (Say), 1823: **MB** [Neave (1934) as *Stenonema tripunctatum* (Banks), 1920; Bednarik and McCafferty (1979)]. **NB** [Whiting (1992)]. **NF** [Newfoundland Island: Bednarik and McCafferty (1979)]. **NS** [Petersen et al. (1985)]. **NW** [Moore (1977) as *Stenonema tripunctatum* (Banks), 1910]. **ON** [Clemens (1913) as *Heptagenia tripunctata* Banks, 1910; Bednarik and McCafferty (1979)]. **PQ** [Provancher (1876) as *Baetis*; McDunnough (1925a) as *Ecdyonurus tripunctatus* (Banks), 1910]. **SA** [Oliver (1960) as *Stenonema tripunctatum* (Banks), 1910; Whiting and Sheard (1990)].

Stenonema flaveolum (Pictet), 1843 nomen dubium: **ON** [Hagen (1861) as *Baetis*].

Stenonema ithaca (Clemens & Leonard), 1924: **ON** [Ide (1930) as *Ecdyonurus*]. **PQ** [McDunnough (1933) as *Ecdyonurus*].

Stenonema luteum (Clemens), 1913: **NB** [Petersen (1989)]. **NS** [Petersen et al. (1985)]. **ON** [Clemens (1913) as *Heptagenia*, type]. **PQ** [McDunnough (1925a) as *Ecdyonurus*].

Stenonema mediopunctatum (McDunnough), 1926: **MB** [Friesen et al. (1980) as *Stenonema nepotellum* (McDunnough), 1933; Gyselman (1980) as *Stenonema nepotellum* (McDunnough), 1933; Flannagan and Flannagan (1982)]. **NB** [Petersen and Martin-Robichaud (1986)]. **ON** [Banks (1910) as *Heptagenia terminata* (Walsh), 1862; McDunnough (1926a) as *Ecdyonurus*, type; McDunnough (1933a) as *Ecdyonurus nepotellus* McDunnough, 1933]. **PQ** [McDunnough (1933a) as *Ecdyonurus nepotellus* McDunnough, 1933, type; Bednarik and McCafferty (1979)].

Stenonema mexicanum (Ulmer), 1920: **MB** [Friesen et al. (1980) as *Stenonema* cf *integrum* (McDunnough), 1924]. **ON** [Walley (1927) as *Ecdyonurus integer* (McDunnough), 1924]. **PQ** [Walley (1927) as *Ecdyonurus integer* (McDunnough), 1924].

Stenonema modestum (Banks), 1910: **NB** [McDunnough (1933a) as *Ecdyonurus rubromaculatus* (Clemens), 1913; Petersen and Martin-Robichaud (1986)]. **NS** [McDunnough (1933a) as

Ecdyonurus rubromaculatus (Clemens), 1913; Petersen et al. (1987)]. **ON** [Clemens (1913) misidentified as *Heptagenia flavescens* (Walsh), 1862; Clemens (1913) as *Heptagenia rubromaculata* Clemens, 1913, type; Walley (1927) as *Ecdyonurus ruber* McDunnough, 1926; Bednarik and McCafferty (1979)]. **PQ** [McDunnough (1925a) as *Ecdyonurus rubromaculatus* (Clemens), 1913; McDunnough (1926a) as *Ecdyonurus ruber* McDunnough, 1926, type; Bednarik and McCafferty (1979)].

Stenonema pulchellum (Walsh), 1862: **ON** [Hagen (1861) misidentified as *Heptagenia luridipennis* (Burmeister), 1839; Walley (1927) as *Ecdyonurus*]. **PQ** [Eaton (1871) misidentified as *Heptagenia luridipennis* (Burmeister), 1839].

Stenonema terminatum (Walsh), 1862: **AB** [Walley (1927) as *Ecdyonurus*]. **BC** [Lewis (1974)]. **MB** [McDunnough (1925a) as *Ecdyonurus*; Lewis (1974) as *Stenonema bipunctatum* (McDunnough), 1926]. **NF** [Labrador: larvae, Raft River, W of Churchhill Falls, Rt 500, 2 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [adults, Hants Co., Nine Mile River, Hwy 14, 23 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **ON** [McDunnough (1926a) as *Ecdyonurus bipunctatus* McDunnough, 1926, type; McDunnough (1926a) as *Ecdyonurus placita* (Banks), 1910; Bednarik and McCafferty (1979)]. **PE** [larvae, Queens Co., Dunk River, Hwy 232, 29 June 1994, C. Goforth (CSU)]. **PQ** [Provancher (1876) misidentified as *Baetis interpunctatum* Say, 1839; Provancher (1878) as *Heptagenia*; McDunnough (1926a) as *Ecdyonurus placita* (Banks), 1910; Harper and Harper (1976) as *Stenonema bipunctatum* (McDunnough), 1926]. **SA** [Dosdall and Lehmkuhl (1989a, 1989b)].

Stenonema vicarium (Walker), 1853: **AB** Barton (1980)]. **MB** [Bednarik and McCafferty (1979)]. **NB** [McDunnough (1933a) as *Ecdyonurus fuscus* (Clemens), 1913; Walley (1927) as *Ecdyonurus*]. **NF** [Newfoundland Island: Larson and Colbo (1983). Labrador: larvae and adults, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, Rapid Brook, Hwy 500 E of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, Unknown River, Twin Falls rd. 21 mi W of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Walker (1853) as *Baetis tessellata* Walker, 1853, type; Bednarik and McCafferty (1979)]. **NW** [Cobb and Flannagan (1980)]. **ON** [Clemens (1913) as *Heptagenia fusca* Clemens, 1913, type; Walley (1927) as *Ecdyonurus*; McDunnough (1933a) as *Ecdyonurus rivulicolus* McDunnough, 1933]. **PE** [adults, Queens Co., Dunk River, Hwy 232, 29 June 1994, C. Goforth (CSU)]. **PQ** [Eaton (1871) as *Heptagenia*; McDunnough (1925a, 1925b) as *Ecdyonurus fuscus* (Clemens), 1913; McDunnough (1933a) as *Ecdyonurus rivulicolus* McDunnough, 1933, type]. **SA** [Lehmkuhl (1976a)].

ISONYCHIIDAE

Isonychia bicolor (Walker), 1853: **MB** [Friesen et al. (1980); Friesen et al. (1980) as *Isonychia harperi* Traver, 1934]. **NB** [adults, Magaguadavic River, Hwy 3, Brockway, 30 June 1995, S. Schuler (CSU)]. **NF** [Labrador: all adults, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); Miron River, Hwy 500 E of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); Raft River, Hwy 500, 34 mi N of Churchhill Falls, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [larvae, Lunenberg Co., Gold River at New Ross, 23 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **ON** [Walker (1853) as *Palingenia*, type; Clemens (1913) as *Chirotenetes albomanicatus* (Needham), 1905; Traver (1935a) as *Isonychia christina* Traver, 1934]. **PQ** [McDunnough (1925a); Traver (1935a) as *Isonychia christina* Traver, 1934].

Isonychia campestris McDunnough, 1931: **AB** [McDunnough (1931d) as *Isonychia sicca campestris* McDunnough, 1931, type]. **MB** [McDunnough (1931d) as *Isonychia sicca campestris* McDunnough, 1931]. **SA** [McDunnough (1931d) as *Isonychia sicca campestris* McDunnough, 1931; Kondratieff and Voshell (1984)].

Isonychia rufa McDunnough, 1931: **MB** [Friesen et al. (1980)].

Isonychia sicca (Walsh), 1862: **MB** [McDunnough (1925a)]. **ON** [Ide (1930)].

LEPTOHYPHIDAE

Tricorythodes allectus (Needham), 1905: **MB** [Friesen et al. (1980)]. **NB** [Petersen and Martin-Robichaud (1986) as *Tricorythodes atratus* (McDunnough), 1923]. **NF** [Newfoundland Island: Berner (1959) as *Tricorythodes atratus* (McDunnough), 1923]. **ON** [Clemens (1913) as *Tricorythus*; Ide (1935b) as *Tricorythodes atratus* (McDunnough), 1923]. **PQ** [McDunnough (1923) as *Tricorythus atratus* McDunnough, 1923, type].

Tricorythodes cobbi Alba-Tercedor and Flannagan, 1995: **MB** [Alba-Tercedor and Flannagan (1995), type].

Tricorythodes minutus Traver, 1935: **AB** [McDunnough (1931e) as *Tricorythodes explicatus* (Eaton), 1892; Clifford et al (1973)]. **BC** [McDunnough (1939) as *Tricorythodes fallacina* McDunnough, 1939, type; Scudder (1975)]. **ON** [McDunnough (1931e) as *Tricorythodes explicatus* (Eaton), 1892; Traver (1935a) as *Tricorythodes fallax* Traver, 1935]. **PQ** [McDunnough (1931e) as *Tricorythodes explicatus* (Eaton), 1892; Traver (1935a) as *Tricorythodes fallax* Traver, 1935; Dulude (1992)]. **SA** [McDunnough (1931e) as *Tricorythodes explicatus* (Eaton), 1892; Traver (1935a) as *Tricorythodes fallax* Traver, 1935; Dosdall and Lehmkuhl (1989a, 1989b)].

Tricorythodes mosegus Alba-Tercedor and Flannagan, 1995: **MB** [Alba-Tercedor and Flannagan (1995), type].

Tricorythodes stygiatus McDunnough, 1931: **PQ** [McDunnough (1931e), type].

LEPTOPHLEBIIDAE

Choroterpes albiannulata McDunnough, 1924: **AB** [McDunnough (1924b), type]. **SA** [Lehmkuhl (1976a)].

Choroterpes basalis (Banks), 1900: **ON** [Clemens (1913); Spieth (1938) as *Choroterpes fusca* Spieth, 1938, type]. **PQ** [Banks (1900) as *Leptophlebia*, type].

Habrophlebia vibrans Needham, 1907: **NB** [Petersen (1989)]. **NF** [Newfoundland Island: Larson and Colbo (1983)]. **NS** [Petersen et al. (1987)]. **ON** [McDunnough (1925a, 1925b)]. **PQ** [McDunnough (1925a)].

Habrophlebiodes americana (Banks), 1903: **NB** [Petersen (1989)]. **ON** [Walley (1927)]. **PQ** [McDunnough (1925a, 1925b)].

Leptophlebia cupida (Say), 1823: **AB** [McDunnough (1925a) as *Blasturus*]. **BC** [McDunnough (1925a) as *Leptophlebia pallipes* (Walker), 1853; Clemens et al. (1939) as *Blasturus*]. **MB** [McDunnough (1925a) as *Blasturus*]. **NB** [Whiting (1992)]. **NF** [Newfoundland Island: Walker (1853) as *Ephemera hebes* Walker, 1853, type; Hagen (1861) as *Baetis ignava* Hagen, 1861, type; Berner (1959). Labrador: adults, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, stream entering Moosehead lake, Hwy 500, E of Labrador City, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU);

adult, Miron River, Hwy 500, E of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adults, Raft River, Hwy 500, 34 mi N of Churchhill Falls, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adults, West Mechin River, Hwy, 500, 32 mi E of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, Unknown River, Twin Falls rd, 21 mi W of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Walker (1853) as *Palingenia concinna* Walker, 1853, type; Walker (1853) as *Palingenia pallipes* Walker, 1853, type; Eaton (1871)]. **ON** [Clemens (1913) as *Blasturus*]. **PE** [adults, Prince Co., tributary to Grand River, Hwy 177, S of Wellington, 18 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1925a, 1925b) as *Blasturus*]. **SA** [Hagen (1863) as *Potamanthus*].

Leptophlebia gravastella (Eaton), 1884: **BC** [McDunnough (1925a) as *Blasturus*].

Leptophlebia johnsoni McDunnough, 1924: **ON** [Walley (1927)]. **PQ** [McDunnough (1925a, 1925b)].

Leptophlebia nebulosa (Walker), 1853: **AB** [McDunnough (1925a) as *Blasturus*]. **BC** [McDunnough (1925a) as *Blasturus*]. **MB** [Neave (1934)]. **NB** [McDunnough (1925a) as *Blasturus*]. **NS** [adult, Colchester Co., Bailey's Brook, Rt 256 W of Falls, 3 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NW** [Wiens et al. (1975)]. **ON** [Walker (1853) as *Palingenia*, type]. **PQ** [McDunnough (1925a) as *Blasturus*]. **SA** [Hagen (1863) as *Potamanthus*]. **YU** [Harper and Harper (1981)].

Paraleptophlebia adoptiva (McDunnough), 1929: **NB** [Whiting (1992)]. **NF** [Newfoundland Island: Larson and Colbo (1983)]. **NS** [Whiting (1992)]. **ON** [Ide (1930) as *Leptophlebia*]. **PQ** [McDunnough (1929) as *Leptophlebia*, type]. **SA** [Lehmkuhl (1976a)].

Paraleptophlebia bicornuta (McDunnough), 1926: **AB** [McDunnough (1926b) as *Leptophlebia*, type]. **BC** [McDunnough (1926b) as *Leptophlebia*].

Paraleptophlebia brunneipennis (McDunnough), 1924: **BC** [McDunnough (1924b) as *Leptophlebia*].

Paraleptophlebia debilis (Walker), 1853: **AB** [McDunnough (1928a) as *Leptophlebia*]. **BC** [Walley (1927) as *Leptophlebia*]. **MB** [McDunnough (1925a) as *Leptophlebia*]. **NB** [larvae, Miramichi River, 2 September 1950, E.L. Bousefield (PERC)]. **NF** [Newfoundland Island: Larson and Colbo (1983)]. **NS** [Walker (1853) as *Baetis*, type]. **ON** [Walley (1927) as *Leptophlebia*]. **PQ** [McDunnough (1925a, 1925d) as *Leptophlebia*]. **SA** [Lehmkuhl (1976a)]. **YU** [Harper and Harper (1997)].

Paraleptophlebia gregalis (Eaton), 1884: **BC** [McDunnough (1926b) as *Leptophlebia invalida* McDunnough, 1926, type; Walley (1927)].

Paraleptophlebia guttata (McDunnough), 1924: **NB** [Harper and Harper (1986)]. **NS** [Harper and Harper (1986)]. **NW** [Moore (1977)]. **ON** [Walley (1927) as *Leptophlebia*]. **PQ** [McDunnough (1924a), as *Leptophlebia*, type].

Paraleptophlebia heteronea (McDunnough), 1924: **AB** [McDunnough (1924a) as *Leptophlebia*, type]. **BC** [McDunnough (1925a) as *Leptophlebia*].

Paraleptophlebia memorialis (Eaton), 1884: **AB** [McDunnough (1928a) as *Leptophlebia pallipes* Hagen, 1875]. **BC** [McDunnough (1924a) as *Leptophlebia pallipes* Hagen, 1875].

Paraleptophlebia moerens (McDunnough), 1924: **NS** [Harper and Harper (1981)]. **ON** [Walley (1927) as *Leptophlebia*]. **PQ** [McDunnough (1924a) as *Leptophlebia*, type]. **SA** [Lehmkuhl (1976a)]. **YU** [Harper and Harper (1981)].

Paraleptophlebia mollis (Eaton), 1871: **MB** [Friesen et al. (1980)]. **NB** [Petersen (1989)]. **NF** [Labrador: Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adults, Ashuanipi River, Hwy 500, W of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adults, Rapid Brook, Hwy 500, E of

Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Petersen et al. (1987)]. **ON** [McDunnough (1924a) as *Leptophlebia*]. **PE** [larvae and adults, Prince Co., Miminegash River, Hwy 151, 19 June 1993, B.C. Kondratieff and R.W. Baumann (CSU); adults, Kings Co., Morell River, Hwy 320, 20 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [McDunnough (1924a) as *Leptophlebia*].

Paraleptophlebia ontario (McDunnough), 1926: **NB** [adult, Nepisiquit River, Hwy 360, 12 June 1992, M. Menet (CSU)]. **ON** [McDunnough (1926b) as *Leptophlebia*, type]. **PQ** [Harper and Harper (1982)].

Paraleptophlebia praepedita (Eaton), 1884: **AB** [Clifford and Boerger (1974)]. **MB** [McDunnough (1925a) as *Leptophlebia*]. **ON** [Clemens (1915) as *Leptophlebia*]. **PQ** [McDunnough (1925a, 1925b) as *Leptophlebia*]. **SA** [Lehmkuhl (1976a)].

Paraleptophlebia rufivenosa (Eaton), 1884: **BC** [McDunnough (1924b) as *Leptophlebia*].

Paraleptophlebia strigula (McDunnough), 1932: **NS** [Whiting (1992)]. **ON** [McDunnough (1932b) as *Leptophlebia*, type]. **PQ** [Dulude (1992)].

Paraleptophlebia temporalis (McDunnough), 1926: **AB** [Harper and Harper (1986)]. **BC** [McDunnough (1926b) as *Leptophlebia*, type].

Paraleptophlebia vaciva (Eaton), 1884: **BC** [Scudder (1975)].

Paraleptophlebia volitans (McDunnough), 1924: **NS** [Petersen et al. (1987)]. **ON** [McDunnough (1924a) as *Leptophlebia*]. **PQ** [McDunnough (1924a) as *Leptophlebia*, type].

Traverella albertana (McDunnough), 1931: **AB** [McDunnough (1931a) as *Thraulus*, type]. **SA** [McDunnough (1931a) as *Thraulus*].

METRETOPODIDAE

Metretopus borealis (Eaton), 1871: **AB** [McDunnough (1925a, 1925d) as *Metretopus norvegicus* Eaton, 1901; Berner (1978)]. **BC** [Edmunds (1957)]. **MB** [Edmunds (1957)]. **NB** [Berner (1978)]. **NW** [Wiens et al. (1975) as *Metretopus* sp.; Cobb and Flannagan (1980)]. **PQ** [Harper et al. (1975)]. **SA** [Lehmkuhl (1976a)]. **YU** [Harper and Harper (1981)].

Siphloplecton basale (Walker), 1853: **AB** [Clifford and Boerger (1974)]. **MB** [Walker (1853) as *Baetis*, type]. **NB** [McDunnough (1925a)]. **NF** [Labrador: adult, Walsh River, SW of Labrador City, Hwy 530, 11 June 1997, B.C. Kondratieff and R.W. Baumann (CSU); adult, Raft River, Hwy 500, 34 mi N of Churchhill Falls, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **ON** [Clemens (1913) as *Siphlurus flexus* Clemens, 1913, type; McDunnough (1925a)]. **PQ** [McDunnough (1925a)].

Siphloplecton interlineatum (Walsh), 1863: **AB** [Clifford and Boerger (1974)]. **MB** [McDunnough (1924a)]. **NW** [Wiens et al. (1975)]. **SA** [Lehmkuhl (1976a)].

NEOEPHEMERIDAE

Neoephemera bicolor McDunnough, 1925: **ON** [Walley (1927)]. **PQ** [McDunnough (1925d), type].

OLIGONEURIIDAE

Lachlania saskatchewanensis Ide, 1941: **SA** [Ide (1941), type].

POLYMITARCYIDAE

Ephoron album (Say), 1824: **MB** [Say (1824) as *Baetis*, type]. **ON** [Barton and Hynes (1978)]. **SA** [Lehmkuhl (1976a)].
Ephoron leukon Williamson, 1802: **MB** [Gyselman (1980) misidentified as *Ephoron album* (Say), 1824]. **ON** [McDunnough (1926a)]. **PQ** [McDunnough (1926a)].

Tortopus primus (McDunnough), 1924: **MB** [Ide (1941) as *Campsurus manitobensis* Ide, 1941, type]. **SA** [Lehmkuhl (1976a)].

POTAMANTHIDAE

Anthopotamus distinctus (Traver), 1935: **NB** [Whiting (1992)]. **PQ** [Dulude (1992) as *Potamanthus*].
Anthopotamus myops (Walsh), 1863: **MB** [Bae and McCafferty (1991)]. **ON** [Ide (1935a) as *Potamanthus rufous* Argo, 1927; Bae and McCafferty (1991)].
Anthopotamus verticis (Say), 1839: **ON** [Eaton (1885) as *Ecdyurus*; McDunnough (1925a) as *Potamanthus diaphanus* Needham, 1907; Ide (1935a) as *Potamanthus flaveola* (Walsh), 1862; Ide (1935a) as *Potamanthus walkeri* Ide, 1935, type].

PSEUDIRONIDAE

Pseudiron centralis McDunnough, 1931: **AB** [Pescador (1985)]. **MB** [McDunnough (1931a)]. **ON** [Griffiths (1996) as unspecified species of *Pseudiron*; larva, Rainy River, July 1968, R.W. Griffiths (RWG)]. **SA** [Lehmkuhl (1976a)].

SIPHLONURIDAE

Parameletus chelifer Bengtsson, 1908: **MB** [McDunnough (1938)]. **NW** [Harper and Harper (1981)].
Parameletus columbiae McDunnough, 1938: **BC** [McDunnough (1938), type].
Parameletus croesus (McDunnough), 1923: **ON** [McDunnough (1923) as *Siphlonuroides*, type].
Parameletus midas (McDunnough), 1923: **MB** [Harper and Harper (1981)]. **NB** [adult, Gloucester Co., Nepisiquit River, Hwy 360, 17 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **ON** [McDunnough (1923) as *Siphlonuroides*, type]. **PQ** [McDunnough (1930) as *Sparrea* sp.; McDunnough (1932a)].

Siphlonisca aerodromia Needham, 1909: **NF** [Labrador: Fiance (1978)]. **PQ** [Magnin and Harper (1970) as unspecified species of *Siphlonisca*; Hutchinson (1989)].

Siphlonurus alternatus (Say), 1824: **AB** [Walley (1927)]. **MB** [Neave (1934)]. **NF** [Newfoundland Island: Larson and Colbo (1983)]. **NB** [adults, Nepisiquit River, Hwy 360, 12 June 1992, M. Menet (CSU)]. **NS** [Whiting (1992)]. **NW** [Say (1824) as *Baetis*, type; Wiens et al. (1975) as *Siphlonurus* cf. *alternatus*; Harper and Harper (1981)]. **ON** [McDunnough (1925a)]. **PQ** [Provancher (1876) misidentified as *Baetis femorata* Say, 1824; Provancher (1878) as *Siphlurus*]. **SA** [Oliver (1960)]. **YU** [Harper and Harper (1997)].
Siphlonurus autumnalis McDunnough, 1931: **AB** [McDunnough (1931a), type]. **BC** [McDunnough (1931a)].

Siphlonurus barbaroides McDunnough, 1929: **NB** [Whiting (1992)]. **NF** [Labrador: Rapid Brook, Hwy 500, E of Churchhill Falls, 13 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Whiting (1992)]. **PQ** [McDunnough (1929), type].

Siphlonurus barbarus McDunnough, 1924: **NS** [adults, Inverness Co., stream into Jack Gillis Brook, 3 June 1992, F. Reyes (CSU)]. **PQ** [McDunnough (1932a)].

Siphlonurus columbianus McDunnough, 1925: **BC** [McDunnough (1925d), type].

Siphlonurus demaryi Kondratieff and Voshell, 1981: **NB** [adult, Kennebecosis River, Rt 895, 3 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [Kondratieff and Voshell (1981), type].

Siphlonurus marshalli Traver, 1934: **ON** [Williams and Hynes (1976)].

Siphlonurus mirus (Eaton), 1885: **NS** [adult, Inverness Co., Broad Cove River, Hwy 19, Glenville, 21 June 1993, B.C. Kondratieff and R.W. Baumann (CSU); adults, Lunenberg Co., Gold River at New Ross, 23 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **PQ** [Dulude (1992) – no data; adults, Saguenay County, Riviere aux Loups Marlins, above Route 138, 9 August 1982 (CSU)].

Siphlonurus occidentalis (Eaton), 1885: **AB** [McDunnough (1925a); McDunnough (1931a) as *Siphlonurus inflatus* McDunnough, 1931, type]. **BC** [McDunnough (1931a) as *Siphlonurus inflatus* McDunnough, 1931]. **NW** [Wiens et al. (1975) as *Siphlonurus occidentalis inflatus* McDunnough, 1931]. **YU** [Harper and Harper (1981)].

Siphlonurus phyllis McDunnough, 1923: **AB** [McDunnough (1923), type]. **MB** [McDunnough (1925a)]. **NW** [Harper and Harper (1981)]. **ON** [Flannagan and Cobb (1995)]. **PQ** [McDunnough (1930)]. **YU** [Harper and Harper (1997)].

Siphlonurus quebecensis (Provancher), 1878: **NB** [adults, Sunburg Co., Oromocto River, Hwy 101, Tracy, 12 June, 1998, B.C. Kondratieff and R.W. Baumann (CSU); adults, Westmoreland Co., Cecogne River, Rt 126, 12 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NF** [Newfoundland Island: Larson and Colbo (1983). Labrador: adults, Trout River, Hwy 510 N of Pinware, 6 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [adults, Colchester Co., Waughs River, The Falls, Hwy 256, 3 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **ON** [McDunnough (1925a)]. **PQ** [Provancher (1876) misidentified as *Baetis canadensis* Walker, 1853; Provancher (1978) as *Siphlurus*, type].

Siphlonurus rapidus McDunnough, 1924: **NB** [adults, York Co., Pokiok Stream, Hwy 635 below Lake George, 15 June 1993, B.C. Kondratieff and R.W. Baumann (CSU); adults, tributary of Tantrama River, N of Sackville, 18 June 1993, B.C. Kondratieff and R.W. Baumann (CSU); adults, Cunningham Creek, Hwy 7, NW of Nerepsis, 25 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **NF** [Labrador, adults, Ashuanipi River, Hwy 500, W of Ross Bay junction, 12 June 1997, B.C. Kondratieff and R.W. Baumann (CSU)]. **NS** [adult, Cochester Co., Waughs River, The Falls, Hwy 256, 3 June 1998, B.C. Kondratieff and R.W. Baumann (CSU)]. **ON** [Walley (1927)]. **PQ** [McDunnough (1929)].

Siphlonurus securifer McDunnough, 1926: **ON** [McDunnough (1926b), type]. **PQ** [Dulude (1992)].

Siphlonurus spectabilis Traver, 1934: **NW** [Cobb and Flannagan (1980)].

Siphlonurus typicus (Eaton), 1885: **NF** [Labrador: Walley (1927) as *Siphlonurus bernice* [sic] McDunnough, 1923]. **NS** [adults, Kings Co., Butler Lake Brook, below Burke Lake, 23 June 1993, B.C. Kondratieff and R.W. Baumann (CSU)]. **ON** [Walley (1927) as *Siphlonurus bernice* [sic] McDunnough, 1923; Giberson and Mackay (1991)]. **PQ** [McDunnough (1923) as *Siphlonurus berenice* McDunnough, 1923, type; Harper and Harper (1982)].

CHECKLISTS

Footnotes to species:
[1] New record for the province or territory.
[2] New Canadian record.
[3] Originally described from the province or territory.
[4] Endemic to province or territory.
[5] Endemic to Canada.
[6] Also found elsewhere in Canada.
[7] Also found in Palearctic.
[8] Also found in the conterminous United States.
[9] Also found in Alaska.

ALBERTA

ACANTHAMETROPODIDAE
Analetris eximia[6,8]

AMELETIDAE
Ameletus bellulus[3,8], *celer*[3,6,8], *cooki*[6,8], *majusculus*[3,8], *oregonensis*[6,8], *pritchardi*[3,5,6], *similior*[3,6,8], *sparsatus*[3,6,8], *subnotatus*[6,8], *suffusus*[5,6], *validus*[3,6,8,9], *velox*[6,8], *vernalis*[6,8]

AMETROPODIDAE
Ametropus neavei[3,6,8]

BAETIDAE
Acentrella insignificans[6,8], *turbida*[3,6,8]
Acerpenna akataleptos[3,4,5]
Baetis bicaudatus[6,7,8,9], *moffatti*[6,8], *parallelus*[6,8], *persecutor*[5,6], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[6,8], *pallidus*[6,8]
Centroptilum bifurcatum[3,6,8], *conturbatum*[3,6,8]
Diphetor hageni[6,8]
Plauditus armillatus[6,8], *dubius*[6,8], *futilis*[3,4,5], *rubrolateralis*[3,4,5],
Procloeon implicatum[3,6,8], *inanum*[3,5,6], *ingens*[3,6,8], *pennulatum*[6,7,8], *quaesitum*[3,6,8]

BAETISCIDAE
Baetisca lacustris[6,8], *laurentina*[6,8], *obesa*[6,8]

CAENIDAE
Caenis amica[6,8], *latipennis*[6,8], *tardata*[3,6,8], *youngi*[6,8]

EPHEMERELLIDAE
Attenella margarita[6,8]
Drunella coloradensis[6,8,9], *doddsi*[6,8,9], *flavilinea*[3,6,8], *grandis*[6,8,9], *spinifera*[6,8]
Ephemerella aurivillii[6,7,8,9], *inermis*[6,8], *infrequens*[3,6,8,9]
Serratella tibialis[3,6,8,9]
Timpanoga hecuba[6,8], *simplex*[6,8]

EPHEMERIDAE
Ephemera simulans[6,8]
Hexagenia limbata[6,8]

HEPTAGENIIDAE
Acanthomola pubescens[5,6]
Cinygma lyriforme[3,7,8,9]
Cinygmula confusa[3,4,5], *mimus*[6,8], *par*[6,8,9], *ramaleyi*[6,8], *tarda*[3,6,8]
Epeorus albertae[3,6,8], *deceptivus*[3,6,8], *grandis*[3,6,8], *longimanus*[6,8,9]
Heptagenia adaequata[3,5,6], *solitaria*[3,6,8]
Nixe criddlei[8], *simplicioides*[3,6,7,8]
Rhithrogena futilis[3,6,8,9], *hageni*[3,6,8], *jejuna*[6,8], *morrisoni*[6,8], *robusta*[6,8], *virilis*[5,6]
Stenacron interpunctatum[6,8]
Stenonema terminatum[6,8], *vicarium*[6,8]

ISONYCHIIDAE
Isonychia campestris[3,6,8]

LEPTOHYPHIDAE
Tricorythodes minutus[6,8]

LEPTOPHLEBIIDAE
Choroterpes albiannulata[3,6,8]
Leptophlebia cupida[6,8], *nebulosa*[6,8]
Paraleptophlebia bicornuta[3,6,8], *debilis*[6,8], *heteronea*[3,6,8], *memorialis*[6,8], *praepedita*[6,8], *temporalis*[6,8]
Traverella albertana[3,6,8]

METRETOPODIDAE
Metretopus borealis[6,7,8]
Siphloplecton basale[6,8], *interlineatum*[6,8]

PSEUDIRONIDAE
Pseudiron centralis[6,8]

SIPHLONURIDAE
Siphlonurus alternatus[6,7,8], *autumnalis*[3,6,8], *occidentalis*[6,8], *phyllis*[3,5,6]

BRITISH COLUMBIA

AMELETIDAE
Ameletus celer[6,8], *cooki*[6,8], *oregonensis*[6,8], *pritchardi*[5,6], *shepherdi*[3,8], *similior*[6,8], *sparsatus*[6,8], *subnotatus*[6,8], *suffusus*[3,5,6], *validus*[6,8], *vancouverensis*[3,8], *velox*[6,8], *vernalis*[3,6,8]

BAETIDAE
Acentrella insignificans[3,6,8], *turbida*[6,8]
Baetis bicaudatus[6,7,8,9], *bundyae*[1,6,7,9], *moffatti*[6,8], *parallelus*[6,8], *persecutor*[3,5,6], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[6,8]
Centroptilum album[6,8], *bifurcatum*[6,8], *conturbatum*[6,8]

Diphetor hageni[6,8]
Procloeon bellum[6,8], *implicatum*[6,8]

CAENIDAE
Caenis amica[6,8]

EPHEMERELLIDAE
Attenella margarita[1,6,8]
Caudatella heterocaudata[8], *hystrix*[8], *jacobi*[3,8]
Drunella coloradensis[6,8,9], *doddsi*[6,8,9], *flavilinea*[6,8], *grandis*[6,8,9], *pelosa*[8], *spinifera*[3,6,8]
Ephemerella aurivillii[6,7,8,9], *inermis*[6,8], *infrequens*[6,8,9]
Eurylophella lodi[8]
Serratella teresa[8], *tibialis*[6,8,9]
Timpanoga hecuba[6,8]

EPHEMERIDAE
Ephemera simulans[6,8]
Hexagenia limbata[6,8]

HEPTAGENIIDAE
Cinygma integrum[8]
Cinygmula gartrelli[3,4,5], *kootenai*[3,8], *mimus*[6,8], *par*[6,8,9], *ramaleyi*[6,8], *uniformis*[3,6,8]
Epeorus albertae[6,8], *deceptivus*[6,8], *dulciana*[3,8], *grandis*[6,8], *longimanus*[6,8,9], *permagnus*[8]
Heptagenia elegantula[6,8], *flavescens*[6,8], *solitaria*[6,8]
Ironodes arctus[8], *flavipennis*[3,4,5], *nitidus*[8]
Nixe simplicioides[6,7,8]
Rhithrogena hageni[6,8], *jejuna*[6,8], *morrisoni*[6,8], *robusta*[6,8], *virilis*[3,5]
Stenonema terminatum[6,8]

LEPTOHYPHIDAE
Tricorythodes minutus[6,8]

LEPTOPHLEBIIDAE
Leptophlebia cupida[6,8], *gravastella*[8], *nebulosa*[6,8]
Paraleptophlebia bicornuta[6,8], *brunneipennis*[8], *debilis*[6,8], *gregalis*[8], *heteronea*[6,8], *memorialis*[6,8], *rufivenosa*[8], *temporalis*[3,6,8], *vaciva*[8]

METRETOPODIDAE
Metretopus borealis[6,7,8]

SIPHLONURIDAE
Parameletus columbiae[3,8]
Siphlonurus autumnalis[6,8], *columbianus*[3,8], *occidentalis*[6,8]

MANITOBA

AMELETIDAE
Ameletus subnotatus[6,8]

BAETIDAE

Acentrella turbida[6,8]

Acerpenna pygmaea[6,8]

Baetis brunneicolor[6,8], *bundyae*[6,7,9], *flavistriga*[6,8], *hudsonicus*[3,5,6], *intercalaris*[6,8], *pluto*[6,8], *tricaudatus*[6,8,9]

Callibaetis ferrugineus[6,8], *fluctuans*[6,8], *pallidus*[6,8]

Centroptilum album[6,8], *bifurcatum*[6,8], *conturbatum*[6,8], *victoriae*[5,6]

Diphetor hageni[6,8]

Fallceon quilleri[6,8]

Labiobaetis dardanus[3,6,8], *propinquus*[6,8]

Plauditus armillatus[6,8], *dubius*[6,8], *punctiventris*[6,8]

Procloeon convexum[6,8], *inanum*[5,6], *ingens*[6,8], *irrubrum*[3,4,5], *pennulatum*[6,7,8], *quaesitum*[6,8], *rubropictum*[6,8], *rufostrigatum*[3,6,8], *walshi*[8]

BAETISCIDAE

Baetisca lacustris[6,8], *laurentina*[6,8], *obesa*[6,8]

CAENIDAE

Caenis amica[6,8], *latipennis*[6,8], *tardata*[6,8]

EPHEMERELLIDAE

Ephemerella invaria[6,8]

Eurylophella bicolor[6,8], *temporalis*[6,8]

Timpanoga simplex[6,8]

EPHEMERIDAE

Ephemera simulans[6,8]

Hexagenia bilineata[6,8], *limbata*[6,8], *rigida*[6,8]

Pentagenia vittigera[6,8]

HEPTAGENIIDAE

Epeorus albertae[6,8], *vitreus*[6,8]

Heptagenia elegantula[6,8], *flavescens*[6,8], *pulla*[6,8]

Leucrocuta aphrodite[6,8], *hebe*[6,8], *jewetti*[8], *maculipennis*[6,8], *umbratica*[6,8]

Nixe inconspicua[3,6,8], *simplicioides*[6,7,8]

Raptoheptagenia cruentata[6,8]

Rhithrogena pellucida[6,8]

Stenacron gildersleevei[1,2,8], *interpunctatum*[6,8]

Stenonema femoratum[6,8], *mediopunctatum*[6,8], *mexicanum*[6,8], *terminatum*[6,8], *vicarium*[6,8]

ISONYCHIIDAE

Isonychia bicolor[6,8], *campestris*[6,8], *rufa*[8], *sicca*[6,8]

LEPTOHYPHIDAE

Tricorythodes allectus[6,8], *cobbi*[3,4,5], *mosegus*[3,4,5]

LEPTOPHLEBIIDAE

Leptophlebia cupida[6,8], *nebulosa*[6,8]

Paraleptophlebia debilis[6,8], *mollis*[6,8], *praepedita*[6,8]

METRETOPODIDAE
Metretopus borealis[6,7,8]
Siphloplecton basale[3,6,8], *interlineatum*[6,8]

POLYMITARCYIDAE
Ephoron album[3,6,8], *leukon*[1,6,8]
Tortopus primus[6,8]

POTAMANTHIDAE
Anthopotamus myops[6,8]

PSEUDIRONIDAE
Pseudiron centralis[6,8]

SIPHLONURIDAE
Parameletus chelifer[6,7,9], *midas*[5,6]
Siphlonurus alternatus[6,7,8], *phyllis*[5,6]

NEW BRUNSWICK

AMELETIDAE
Ameletus subnotatus[6,8]

ARTHROPLEIDAE
Arthroplea bipunctata[6,8]

BAETIDAE
Acentrella turbida[1,6,8]
Acerpenna macdunnoughi[6,8], *pygmaea*[6,8]
Baetis brunneicolor[6,8], *flavistriga*[6,8], *intercalaris*[6,8], *pluto*[6,8], *rusticans*[6,8], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[6,8]
Centroptilum album[6,8]
Diphetor hageni[6,8]
Heterocloeon curiosum[6,8]
Labiobaetis propinquus[1,6,8]
Plauditus punctiventris[6,8]
Procloeon bellum[1,6,8], *pennulatum*[1,6,7,8], *rubropictum*[1,6,8], *rufostrigatum*[6,8]

BAETISCIDAE
Baetisca laurentina[6,8]

CAENIDAE
Caenis amica[6,8], *latipennis*[6,8]

EPHEMERELLIDAE
Attenella attenuata[6,8], *margarita*[6,8]

Drunella cornuta[6,8], *cornutella*[6,8], *lata*[6,8], *tuberculata*[6,8], *walkeri*[6,8]
Ephemerella aurivillii[6,7,8,9], *dorothea*[6,8], *excrucians*[6,8], *invaria*[6,8], *needhami*[6,8], *rotunda*[6,8], *septentrionalis*[6,8], *subvaria*[6,8]
Eurylophella aestiva[6,8], *bicolor*[6,8], *funeralis*[6,8], *lutulenta*[6,8], *minimella*[6,8], *prudentalis*[6,8], *temporalis*[6,8], *verisimilis*[6,8]
Serratella deficiens[6,8], *molita*[5,6], *serrata*[6,8], *serratoides*[6,8]
Timpanoga simplex[6,8]

EPHEMERIDAE
Ephemera guttulata[1,6,8], *simulans*[1,6,8]
Hexagenia limbata[6,8], *rigida*[6,8]

HEPTAGENIIDAE
Cinygmula subaequalis[6,8,9]
Epeorus pleuralis[6,8], *vitreus*[6,8]
Heptagenia pulla[1,6,8]
Leucrocuta hebe[6,8]
Rhithrogena impersonata[6,8], *jejuna*[6,8]
Stenacron interpunctatum[6,8]
Stenonema femoratum[6,8], *luteum*[6,8], *mediopunctatum*[6,8], *modestum*[6,8], *vicarium*[6,8]

ISONYCHIIDAE
Isonychia bicolor[1,6,8]

LEPTOHYPHIDAE
Tricorythodes allectus[6,8]

LEPTOPHLEBIIDAE
Habrophlebia vibrans[6,8]
Habrophlebiodes americana[6,8]
Leptophlebia cupida[6,8], *nebulosa*[6,8]
Paraleptophlebia adoptiva[6,8], *debilis*[1,6,8], *guttata*[6,8], *mollis*[6,8], *ontario*[1,6,8]

METRETOPODIDAE
Metretopus borealis[6,7,8]
Siphloplecton basale[6,8]

POTAMANTHIDAE
Anthopotamus distinctus[6,8]

SIPHLONURIDAE
Parameletus midas[1,5,6]
Siphlonurus alternatus[1,6,7,8], *barbaroides*[6,8], *demaryi*[1,6,8], *quebecensis*[1,6,8], *rapidus*[1,6,8]

NEWFOUNDLAND (ISLAND)

AMELETIDAE
Ameletus subnotatus[6,8]

BAETIDAE
Acerpenna macdunnoughi[6,8], *pygmaea*[6,8]
Baetis flavistriga[6,8], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[6,8], *pallidus*[1,6,8]
Procloeon convexum[6,8]

CAENIDAE
Caenis amica[6,8]

EPHEMERELLIDAE
Drunella cornuta[1,6,8]
Ephemerella aurivillii[6,7,8,9], *invaria*[1,6,8], *subvaria*[6,8]
Eurylophella funeralis[6,8], *prudentalis*[6,8]

HEPTAGENIIDAE
Epeorus pleuralis[6,8]
Heptagenia pulla[6,8]
Rhithrogena undulata[6,8]
Stenonema femoratum[6,8], *vicarium*[6,8]

LEPTOHYPHIDAE
Tricorythodes allectus[6,8]

LEPTOPHLEBIIDAE
Habrophlebia vibrans[6,8]
Leptophlebia cupida[6,8]
Paraleptophlebia adoptiva[6,8], *debilis*[6,8]

SIPHLONURIDAE
Siphlonurus alternatus[6,7,8], *quebecensis*[6,8]

NEWFOUNDLAND (LABRADOR)

(Footnote 10 = new Labrador record only)

AMELETIDAE
Ameletus tertius[1,6,8]

BAETIDAE
Acentrella lapponica[6,7,9]
Acerpenna macdunnoughi[6,8,10]
Baetis bundyae[6,7,9], *tricaudatus*[6,8,9,10]

BAETISCIDAE
Baetisca laurentina[1,6,8], *rubescens*[1,6,8]

EPHEMERELLIDAE
Drunella cornutella[1,6,8]
Ephemerella aurivillii[6,7,8,9,10], *invaria*[1,6,8], *subvaria*[6,8,10]

Serratella deficiens[1,6,8]

EPHEMERIDAE
Ephemera guttulata[1,6,8]
Litobrancha recurvata[1,6,8]

HEPTAGENIIDAE
Epeorus pleuralis[6,8,10]
Rhithrogena jejuna[6,8]
Stenacron interpunctatum[1,6,8]
Stenonema terminatum[1,6,8], *vicarium*[6,8,10]

ISONYCHIIDAE
Isonychia bicolor[1,6,8]

LEPTOPHLEBIIDAE
Leptophlebia cupida[6,8,10]
Paraleptophlebia mollis[1,6,8]

METRETOPODIDAE
Siphloplecton basale[1,6,8]

SIPHLONURIDAE
Siphlonisca aerodromia[6,8]
Siphlonurus barbaroides[1,6,8], *quebecensis*[6,8,10], *rapidus*[1,6,8], *typicus*[6,8]

NORTHWEST TERRITORIES

AMELETIDAE
Ameletus inopinatus[7], *sparsatus*[1,6,8]

AMETROPODIDAE
Ametropus neavei[6,8]

ARTHROPLEIDAE
Arthroplea bipunctata[6,8]

BAETIDAE
Acentrella insignificans[6,8], *lapponica*[6,7,9]
Acerpenna pygmaea[6,8]
Baetis bicaudatus[6,7,8,9], *bundyae*[3,6,7,9], *flavistriga*[6,8], *foemina*[3,4,5], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[6,8]
Diphetor hageni[6,8]
Procloeon pennulatum[6,7,8]

BAETISCIDAE
Baetisca laurentina[6,8], *obesa*[6,8]

CAENIDAE
Caenis youngi[6,8]

EPHEMERELLIDAE
Drunella coloradensis[6,8,9], *doddsi*[6,8,9]
Ephemerella aurivillii[6,7,8,9], *excrucians*[6,8], *inermis*[6,8], *invaria*[6,8], *mucronata*[6,7]
Eurylophella bicolor[6,8], *temporalis*[6,8]
Serratella tibialis[6,8,9]
Timpanoga simplex[6,8]

EPHEMERIDAE
Ephemera simulans[6,8]
Hexagenia limbata[6,8]

HEPTAGENIIDAE
Cinygmula tarda[6,8]
Epeorus deceptivus[6,8], *grandis*[6,8], *longimanus*[6,8,9]
Heptagenia flavescens[6,8], *pulla*[6,8]
Leucrocuta hebe[6,8], *maculipennis*[6,8]
Rhithrogena jejuna[6,8], *undulata*[6,8]
Stenonema femoratum[6,8], *vicarium*[6,8]

LEPTOPHLEBIIDAE
Leptophlebia nebulosa[6,8]
Paraleptophlebia guttata[6,8]

METRETOPODIDAE
Metretopus borealis[6,8]
Siphloplecton interlineatum[6,8]

SIPHLONURIDAE
Parameletus chelifer[6,7,9]
Siphlonurus alternatus[3,6,7,8], *occidentalis*[6,8], *phyllis*[5,6], *spectabilis*[8]

NOVA SCOTIA

AMELETIDAE
Ameletus tertius[3,6,8]

ARTHROPLEIDAE
Arthroplea bipunctata[6,8]

BAETIDAE
Acerpenna macdunnoughi[6,8], *pygmaea*[6,8]
Baetis brunneicolor[6,8], *flavistriga*[6,8], *intercalaris*[6,8], *pluto*[6,8], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[6,8]
Centroptilum victoriae[3,5,6]
Diphetor hageni[1,6,8]

Labiobaetis frondalis[6,8], *propinquus*[6,8]
Plauditus punctiventris[6,8]
Procloeon bellum[1,6,8], *rivulare*[1,2,8], *rubropictum*[6,8], *rufostrigatum*[6,8]

BAETISCIDAE
Baetisca laurentina[6,8]

CAENIDAE
Brachycercus lacustris[1,6,8]
Caenis diminuta[6,8]

EPHEMERELLIDAE
Attenella attenuata[6,8], *margarita*[6,8]
Drunella cornuta[6,8], *cornutella*[6,8], *lata*[6,8], *tuberculata*[6,8], *walkeri*[6,8]
Ephemerella aurivillii[6,7,8,9], *dorothea*[6,8], *excrucians*[6,8], *invaria*[6,8], *needhami*[6,8], *rotunda*[6,8], *subvaria*[6,8]
Eurylophella aestiva[6,8], *bicolor*[6,8], *bicoloroides*[3,8], *coxalis*[6,8], *funeralis*[6,8], *minimella*[6,8], *prudentalis*[6,8], *temporalis*[6,8], *verisimilis*[6,8]
Serratella deficiens[6,8], *molita*[5,6], *serrata*[6,8], *serratoides*[6,8]
Timpanoga simplex[6,8]

EPHEMERIDAE
Ephemera guttulata[1,6,8], *simulans*[6,8], *varia*[1,6,8]
Hexagenia rigida[1,6,8]

HEPTAGENIIDAE
Cinygmula subaequalis[6,8,9]
Epeorus fragilis[6,8], *pleuralis*[6,8], *vitreus*[6,8]
Heptagenia pulla[6,8]
Leucrocuta hebe[6,8]
Rhithrogena impersonata[6,8], *jejuna*[6,8]
Stenacron interpunctatum[6,8]
Stenonema femoratum[6,8], *luteum*[6,8], *modestum*[6,8], *terminatum*[1,6,8], *vicarium*[6,8]

ISONYCHIIDAE
Isonychia bicolor[1,6,8]

LEPTOPHLEBIIDAE
Habrophlebia vibrans[6,8]
Leptophlebia cupida[6,8], *nebulosa*[1,6,8]
Paraleptophlebia adoptiva[6,8], *debilis*[6,8], *guttata*[6,8], *moerens*[6,8], *mollis*[6,8], *strigula*[6,8], *volitans*[6,8]

SIPHLONURIDAE
Siphlonurus alternatus[6,7,8], *barbaroides*[6,8], *barbarus*[1,6,8], *demaryi*[3,6,8], *mirus*[1,6,8], *quebecensis*[1,6,8], *rapidus*[1,6,8], *typicus*[1,6,8]

ONTARIO

AMELETIDAE
Ameletus ludens[6,8], *subnotatus*[6,8], *walleyi*[3,4,5]

ARTHROPLEIDAE
Arthroplea bipunctata[6,8]

BAETIDAE
Acentrella turbida[6,8]
Acerpenna macdunnoughi[6,8], *pygmaea*[6,8]
Baetis brunneicolor[3,6,8], *flavistriga*[3,6,8], *hudsonicus*[1,5,6], *intercalaris*[6,8], *pluto*[6,8], *rusticans*[6,8], *tricaudatus*[8,9]
Callibaetis ferrugineus[6,8], *fluctuans*[6,8], *pretiosus*[8], *skokianus*[6,8]
Centroptilum album[3,6,8], *bifurcatum*[1,6,8], *minor*[3,8], *semirufum*[3,6,8], *triangulifer*[3,6,8], *victoriae*[5,6]
Diphetor hageni[6,8]
Heterocloeon curiosum[3,6,8], *frivolum*[6,8]
Labiobaetis dardanus[6,8], *frondalis*[6,8], *longipalpus*[8], *propinquus*[6,8]
Plauditus armillatus[3,6,8], *cestus*[1,2,8], *cinctutus*[6,8], *dubius*[6,8], *punctiventris*[3,6,8], *virilis*[3,6,8]
Procloeon bellum[6,8], *convexum*[3,6,8], *fragile*[3,6,8], *insignificans*[3,4,5], *mendax*[8], *ozburni*[6,8], *rubropictum*[3,6,8], *simile*[6,8], *simplex*[6,8], *viridoculare*[1,2,8]

BAETISCIDAE
Baetisca lacustris[3,6,8], *laurentina*[6,8], *obesa*[6,8]

CAENIDAE
Brachycercus lacustris[6,8]
Caenis amica[6,8], *diminuta*[6,8], *hilaris*[8], *latipennis*[6,8], *punctata*[6,8], *youngi*[1,6,8]

EPHEMERELLIDAE
Attenella attenuata[6,8]
Drunella cornuta[6,8], *tuberculata*[6,8], *walkeri*[3,6,8]
Ephemerella aurivillii[6,8,9], *excrucians*[6,8], *invaria*[3,6,8], *needhami*[6,8], *rotunda*[6,8], *septentrionalis*[3,6,8], *subvaria*[6,8]
Eurylophella aestiva[6,8], *bartoni*[3,4,5], *bicolor*[3,6,8], *coxalis*[6,8], *enoensis*[8], *funeralis*[6,8], *lutulenta*[3,6,8], *minimella*[6,8], *prudentalis*[6,8], *temporalis*[3,6,8], *verisimilis*[6,8]
Serratella deficiens[6,8], *serrata*[6,8], *serratoides*[6,8], *sordida*[6,8]
Timpanoga simplex[6,8]

EPHEMERIDAE
Ephemera guttulata[6,8], *simulans*[6,8], *varia*[6,8]
Hexagenia atrocaudata[3,8], *bilineata*[6,8], *limbata*[6,8], *rigida*[3,6,8]
Litobrancha recurvata[6,8]
Pentagenia vittigera[1,6,8]

HEPTAGENIIDAE
Anepeorus simplex[1,2,8]
Epeorus albertae[1,6,8], *pleuralis*[6,8], *punctatus*[3,6,8], *suffusus*[6,8], *vitreus*[3,6,8]

Heptagenia diabasia[1,6,8], *flavescens*[6,8], *marginalis*[6,8], *pulla*[3,6,8]
Leucrocuta aphrodite[6,8], *hebe*[6,8], *juno*[6,8], *maculipennis*[6,8], *minerva*[6,8], *walshi*[3,6,8]
Nixe horrida[3,4,5], *inconspicua*[6,8], *lucidipennis*[3,6,8], *perfida*[3,8]
Rhithrogena impersonata[6,8], *jejuna*[3,6,8], *pellucida*[1,6,8]
Stenacron candidum[6,8], *carolina*[6,8], *interpunctatum*[3,6,8]
Stenonema exiguum[8], *femoratum*[6,8], *flaveolum* nomen dubium[8], *ithaca*[6,8], *luteum*[3,6,8], *mediopunctatum*[3,6,8], *mexicanum*[6,8], *modestum*[6,8], *pulchellum*[6,8], *terminatum*[6,8], *vicarium*[6,8]

ISONYCHIIDAE
Isonychia bicolor[3,6,8], *sicca*[6,8]

LEPTOHYPHIDAE
Tricorythodes allectus[6,8], *minutus*[6,8]

LEPTOPHLEBIIDAE
Choroterpes basalis[6,8]
Habrophlebia vibrans[6,8]
Habrophlebiodes americana[6,8]
Leptophlebia cupida[6,8], *johnsoni*[6,8], *nebulosa*[3,6,8]
Paraleptophlebia adoptiva[6,8], *debilis*[6,8], *guttata*[6,8], *moerens*[6,8], *mollis*[6,8], *ontario*[3,6,8], *praepedita*[6,8], *strigula*[3,6,8], *volitans*[6,8]

METRETOPODIDAE
Siphloplecton basale[6,8]

NEOEPHEMERIDAE
Neoephemera bicolor[6,8]

POLYMITARCYIDAE
Ephoron album[6,8], *leukon*[6,8]

POTAMANTHIDAE
Anthopotamus myops[6,8], *verticis*[8]

PSEUDIRONIDAE
Pseudiron centralis[1,6,8]

SIPHLONURIDAE
Parameletus croesus[3,4,5], *midas*[3,5,6]
Siphlonurus alternatus[6,7,8], *marshalli*[8], *phyllis*[5,6], *quebecensis*[6,8], *rapidus*[6,8], *securifer*[3,6,8], *typicus*[6,8]

PRINCE EDWARD ISLAND

BAETIDAE
Baetis brunneicolor[1,6,8], *flavistriga*[1,6,8], *tricaudatus*[1,6,8,9]
Callibaetis ferrugineus[1,6,8]

EPHEMERELLIDAE

Ephemerella aurivillii[1,6,8,9], *dorothea*[1,6,8], *invaria*[6,8]

HEPTAGENIIDAE

Cinygmula subaequalis[1,6,8,9]
Epeorus pleuralis[1,6,8]
Stenacron interpunctatum[1,6,8]
Stenonema terminatum[1,6,8], *vicarium*[1,6,8]

LEPTOPHLEBIIDAE

Leptophlebia cupida[1,6,8]
Paraleptophlebia mollis[1,6,8]

QUEBEC

AMELETIDAE

Ameletus browni[3,8], *lineatus*[8], *ludens*[6,8], *subnotatus*[6,8], *tertius*[6,8]

ARTHROPLEIDAE

Arthroplea bipunctata[6,8]

BAETIDAE

Acentrella lapponica[6,7,9], *turbida*[6,8]
Acerpenna macdunnoughi[3,6,8], *pygmaea*[3,6,8]
Baetis brunneicolor[6,8], *bundyae*[6,7,9], *flavistriga*[6,8], *intercalaris*[6,8], *pluto*[3,6,8], *rusticans*[3,6,8], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[6,8], *fluctuans*[6,8], *skokianus*[6,8]
Centroptilum album[6,8], *semirufum*[6,8], *triangulifer*[6,8]
Diphetor hageni[6,8]
Heterocloeon curiosum[6,8], *frivolum*[3,6,8]
Labiobaetis dardanus[6,8], *frondalis*[3,6,8], *propinquus*[6,8]
Plauditus armillatus[6,8], *cinctutus*[3,6,8], *dubius*[6,8], *punctiventris*[6,8], *virilis*[6,8]
Procloeon bellum[3,6,8], *caliginosum*[3,8], *fragile*[6,8], *ingens*[6,8], *intermediale*[3,8], *ozburni*[3,6,8], *rubropictum*[6,8], *rufostrigatum*[6,8], *simile*[3,6,8], *simplex*[3,6,8]

BAETISCIDAE

Baetisca callosa nomen dubium[8], *carolina*[8], *lacustris*[6,8], *laurentina*[3,6,8], *rubescens*[3,6,8]

CAENIDAE

Brachycercus flavus[8], *lacustris*[6,8]
Caenis amica[6,8], *candida*[3,4,5], *diminuta*[6,8], *latipennis*[6,8], *punctata*[3,6,8]

EPHEMERELLIDAE

Attenella attenuata[3,6,8]
Drunella cornuta[6,8], *cornutella*[3,6,8], *lata*[3,6,8], *tuberculata*[6,8], *walkeri*[6,8]
Ephemerella aurivillii[6,7,8,9], *dorothea*[6,8], *excrucians*[6,8], *fratercula*[3,4,5], *invaria*[6,8], *needhami*[3,6,8], *quebecensis*[3,4,5], *rotunda*[6,8], *septentrionalis*[6,8], *subvaria*[3,6,8]

Eurylophella aestiva[3,6,8], *bicolor*[6,8], *coxalis*[3,6,8], *funeralis*[3,6,8], *lutulenta*[6,8], *minimella*[3,6,8], *prudentalis*[3,6,8], *temporalis*[6,8], *verisimilis*[3,6,8]
Serratella deficiens[6,8], *molita*[3,5,6], *serrata*[6,8], *serratoides*[3,6,8], *sordida*[3,6,8]
Timpanoga simplex[3,6,8]

EPHEMERIDAE

Ephemera guttulata[6,8], *simulans*[6,8], *varia*[6,8]
Hexagenia bilineata[6,8], *limbata*[6,8], *rigida*[6,8]
Litobrancha recurvata[6,8]

HEPTAGENIIDAE

Epeorus fragilis[6,8], *pleuralis*[6,8], *punctatus*[6,8], *suffusus*[3,6,8], *vitreus*[6,8]
Heptagenia diabasia[6,8], *manifesta* nomen dubium[8], *marginalis*[6,8], *pulla*[6,8]
Leucrocuta aphrodite[3,6,8], *hebe*[3,6,8], *juno*[3,6,8], *minerva*[3,6,8], *umbratica*[3,6,8], *walshi*[6,8]
Nixe inconspicua[6,8], *rusticalis*[3,6,8]
Rhithrogena amica[8], *anomala*[3,8], *brunneotincta*[3,8], *gaspeensis*[3,4,5], *impersonata*[3,6,8], *jejuna*[6,8]
Stenacron candidum[6,8], *carolina*[6,8], *interpunctatum*[6,8]
Stenonema femoratum[6,8], *ithaca*[6,8], *luteum*[6,8], *mediopunctatum*[6,8], *modestum*[6,8], *pulchellum*[1,6,8], *terminatum*[6,8], *vicarium*[6,8]

ISONYCHIIDAE

Isonychia bicolor[6,8]

LEPTOHYPHIDAE

Tricorythodes allectus[6,8], *minutus*[6,8], *stygiatus*[3,8]

LEPTOPHLEBIIDAE

Choroterpes basalis[6,8]
Habrophlebia vibrans[6,8]
Habrophlebiodes americana[6,8]
Leptophlebia cupida[6,8], *johnsoni*[6,8], *nebulosa*[6,8]
Paraleptophlebia adoptiva[3,6,8], *debilis*[6,8], *guttata*[3,6,8], *moerens*[3,6,8], *mollis*[6,8], *ontario*[6,8], *praepedita*[6,8], *strigula*[6,8], *volitans*[3,6,8]

METRETOPODIDAE

Metretopus borealis[6,7,8]
Siphloplecton basale[6,8]

NEOEPHEMERIDAE

Neoephemera bicolor[3,6,8]

POLYMITARCYIDAE

Ephoron leukon[6,8]

POTAMANTHIDAE

Anthopotamus distinctus[6,8]

SIPHLONURIDAE
Parameletus midas[5,6]
Siphlonisca aerodromia[6,8]
Siphlonurus alternatus[6,7,8], *barbaroides*[3,6,8], *barbarus*[6,8], *mirus*[6,8], *phyllis*[5,6], *quebecensis*[3,6,8], *rapidus*[6,8], *securifer*[6,8], *typicus*[6,8]

SASKATCHEWAN

ACANTHAMETROPODIDAE
Analetris eximia[6,8]

AMELETIDAE
Ameletus oregonensis[6,8]

AMETROPODIDAE
Ametropus albrighti[8], *neavei*[6,8]

BAETIDAE
Acentrella insignificans[1,6,8], *turbida*[1,6,8]
Acerpenna pygmaea[1,6,8]
Apobaetis indeprensus[1,2,8]
Baetis brunneicolor[1,6,8], *flavistriga*[1,6,8], *hudsonicus*[1,5,6], *tricaudatus*[6,8,9]
Callibaetis ferrugineus[1,6,8], *pallidus*[6,8], *skokianus*[6,8]
Camelobaetidius warreni[8]
Centroptilum bifurcatum[1,6,8], *victoriae*[1,5,6]
Diphetor hageni[1,6,8]
Fallceon quilleri[6,8]
Labiobaetis dardanus[1,6,8], *propinquus*[1,6,8]
Plauditus armillatus[1,6,8], *dubius*[1,6,8], *punctiventris*[1,6,8], *virilis*[1,6,8]
Procloeon pennulatum[6,7,8], *quaesitum*[1,6,8]

BAETISCIDAE
Baetisca lacustris[6,8], *obesa*[6,8]

CAENIDAE
Brachycercus prudens[3,8]
Caenis amica[6,8], *latipennis*[6,8], *tardata*[6,8], *youngi*[6,8]

EPHEMERELLIDAE
Drunella grandis[6,8,9]
Ephemerella aurivillii[6,8,9], *inermis*[6,8]
Eurylophella temporalis[6,8]
Timpanoga lita[8], *simplex*[6,8]

EPHEMERIDAE
Ephemera simulans[6,8]
Hexagenia limbata[6,8]

HEPTAGENIIDAE
Acanthomola pubescens[3,5,6]
Anepeorus rusticus[3,8]
Cinygmula mimus[6,8]
Epeorus longimanus[6,8,9]
Heptagenia adaequata[3,5,6], *diabasia*[6,8], *elegantula*[6,8], *flavescens*[6,8], *pulla*[6,8], *solitaria*[6,8]
Leucrocuta hebe[6,8]
Macdunnoa nipawinia[3,4,5]
Nixe inconspicua[6,8], *lucidipennis*[6,8], *rusticalis*[6,8]
Raptoheptagenia cruentata[6,8]
Rhithrogena jejuna[6,8], *undulata*[6,8]
Stenacron interpunctatum[6,8]
Stenonema femoratum[6,8], *terminatum*[6,8], *vicarium*[6,8]

ISONYCHIIDAE
Isonychia campestris[6,8]

LEPTOHYPHIDAE
Tricorythodes minutus[6,8]

LEPTOPHLEBIIDAE
Choroterpes albiannulata[6,8]
Leptophlebia cupida[6,8], *nebulosa*[6,8]
Paraleptophlebia adoptiva[6,8], *debilis*[6,8], *moerens*[6,8], *praepedita*[6,8]
Traverella albertana[6,8]

METRETOPODIDAE
Metretopus borealis[6,7,8]
Siphloplecton interlineatum[6,8]

OLIGONEURIIDAE
Lachlania saskatchewanensis[3,8]

POLYMITARCYIDAE
Ephoron album[6,8]
Tortopus primus[6,8]

PSEUDIRONIDAE
Pseudiron centralis[6,8]

SIPHLONURIDAE
Siphlonurus alternatus[6,7,8]

YUKON TERRITORY

BAETIDAE
Acentrella insignificans[6,8]
Baetis bicaudatus[6,7,8,9], *bundyae*[6,7,9], *tricaudatus*[6,8,9]

Callibaetis ferrugineus[6,8]
Labiobaetis propinquus[6,8]
Procloeon ingens[6,8]

CAENIDAE
Caenis youngi[6,8]

EPHEMERELLIDAE
Drunella coloradensis[6,8,9], *doddsi*[6,8,9], *grandis*[6,8,9]
Ephemerella mucronata[6,7]

HEPTAGENIIDAE
Cinygmula mimus[6,8], *par*[6,8,9], *ramaleyi*[6,8], *uniformis*[1,6,8]
Epeorus grandis[6,8], *longimanus*[6,8,9]
Heptagenia pulla[6,8]
Rhithrogena futilis[6,8,9], *undulata*[6,8]

LEPTOPHLEBIIDAE
Leptophlebia nebulosa[6,8]
Paraleptophlebia debilis[6,8], *moerens*[6,8]

METRETOPODIDAE
Metretopus borealis[6,7,8]

SIPHLONURIDAE
Siphlonurus alternatus[6,7,8], *occidentalis*[6,8], *phyllis*[5,6]

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FIELD OBSERVATIONS OF NON-TARGET FEEDING BY *GALERUCELLA CALMARIENSIS* [COLEOPTERA: CHRYSOMELIDAE], AN INTRODUCED BIOLOGICAL CONTROL AGENT OF PURPLE LOOSESTRIFE, *LYTHRUM SALICARIA* [LYTHRACEAE]

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Abstract

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Purple loosestrife, *Lythrum salicaria* L., is a herbaceous wetland perennial native to Eurasia. It is an invasive species of temperate wetland ecosystems in North America. In 1992, three species of insect herbivores from Europe, including *Galerucella calmariensis* L. and *G. pusilla* Duftschmidt were released as classical biological control agents against purple loosestrife. Host range testing had shown that these species might attack native North American species, such as *Lythrum alatum* Pursh., and *Decodon verticillatus* (L.) Ell., but review panels from the USDA and Agriculture Canada concluded that the benefits of controlling purple loosestrife outweighed potential risks to non-target plant species. The Royal Botanical Garden (RBG) properties are the site of 1993 releases of both imported *Galerucella* species. Extremely large populations of beetles (>500 egg masses/m^2) can now be found near the release areas. In late May 1998, feeding by adult *G. calmariensis* was observed on *D. verticillatus* cuttings growing outdoors at a RBG nursery. As well, egg masses of *G. calmariensis* were taken from *L. alatum* at RBG and were reared to adults on this host plant. Following these observations, all three plant species were monitored for attack through the first and second generation of the *Galerucella* beetles. Purple loosestrife plants sustained moderate to total defoliation in all areas monitored at RBG. *L. alatum* and *D. verticillatus* were only slightly affected by feeding activities of *Galerucella* beetles. Several plants of each non-target species sustained slight adult feeding damage and about 15 egg masses were found on the several hundred plants observed through the summer. No late-instar larvae were observed to develop on these plants in the field. We believe that non-target feeding by *G. calmariensis* represented a short-term "spill-over" effect, but further studies are required to evaluate this phenomenon more rigorously.

Introduction

Purple loosestrife, *Lythrum salicaria* L., is a herbaceous, wetland perennial that is native to Eurasia. It was introduced to the east coast of North America early in the nineteenth century (Stuckey 1980). Large populations now occur in wetlands across eastern North America and the plant has become established in temperate wetland habitats across the continent (White et al. 1993). In North America, dominant, persistent stands of purple loosestrife can displace resident plant species (Thompson et al. 1987; White et al. 1993; Mal et al. 1997). Large-scale displacement

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of native plants by exotic species can result in permanent, deleterious changes to natural areas (Schmitz and Simberloff 1997). Based on its history on this continent, purple loosestrife is thought to be a harmful invader of Nearctic wetland ecosystems (Thompson et al. 1987; White et al. 1993).

A classical biological control program was initiated against this plant in the mid 1980's, and, in 1992, three species of insect herbivores from Europe, *Hylobius transversovittatus* Goeze [Coleoptera: Curculionidae], *Galerucella calmariensis* L. and its congener, *G. pusilla* Duftschmidt [Coleoptera: Chrysomelidae] were approved for release in North America (Hight et al. 1995). Host range testing showed that, in the absence of purple loosestrife, all three species could feed and oviposit on several related, native North American species, including, *Lythrum alatum* Pursh., winged loosestrife, and *Decodon verticillatus* (L.) Ell., swamp loosestrife, [both Lythraceae] (Kok et al. 1992; Blossey et al. 1994a,b). Review panels from the USDA and Agriculture Canada concluded that the potential benefits of controlling purple loosestrife outweighed risks to non-target plant species (Blossey et al. 1994a,b). They believed that non-target species were unlikely to be threatened by the *Galerucella* species in the field, as these beetles had strongly preferred *L. salicaria* in "choice" tests between this plant and non-target species (Blossey et al. 1994b). Despite approval to release the biological control agents, concerns remained as to the actual host choices that would be made by the agents after being released in North America (Kok et al. 1992; Blossey et al. 1994b; Dale 1998).

From 1992 to 1997, the Ontario Biological Control Program against purple loosestrife (Ontario Program) released approximately 320,000 beetles (*G. calmariensis* and *G. pusilla*) at over 200 sites around the province. By 1997, beetle populations at 15–18 of these sites had increased over 1000-fold (Ontario Program, unpublished data). Purple loosestrife plants at these sites sustained reductions in flowering and biomass of over 95%, with populations being replaced by species such as cattails, *Typha* spp., and reed canary grass, *Phalaris arundinacea* L. (Ontario Program, unpublished data).

In 1993, 1600 adult *Galerucella* (800 of each imported species; 1:1 sex ratio) were released at the Royal Botanical Gardens (RBG) in Burlington, Ontario. Large beetle populations have spread from the initial release sites and now occur on purple loosestrife throughout the RBG properties (Bowen 1998). On 19 May 1998, feeding by adult beetles resembling the released *Galerucella* species was observed on small cuttings of *D. verticillatus* growing outdoors at a RBG nursery (Lyall Rudderham, pers. comm.).

Evidence of non-target feeding by *Galerucella* species could be of great concern to the (over 25) North American biocontrol programs that have released the imported *Galerucella* against purple loosestrife. Moreover, observations of non-target feeding by biological control agents in field situations may support recent assertions of the unpredictability of the classical biological control of exotic weeds (Simberloff and Stiling 1996; Louda et al. 1997; Strong 1997). The following paper presents one season's data on the incidence of non-target feeding by *G. calmariensis*. The data reported here should not be taken as the "final word", and more investigations of this phenomena will be needed. However, with so many North American programs using *Galerucella* beetles, and with the current challenges to the practice of biological control, it is important that practitioner and critic alike be made aware of this phenomena in a timely manner.

Materials and Methods

The RBG Sites

The choice of sites was determined by the availability of each of the actual or potential host plant species inside a "zone of occupation" by the beetles on the RBG properties.

Mercer's Glen is a small, shallow pond located about 1 km from Lake Ontario near Cootes Paradise and Hamilton Harbour. In the early 1990's, this area supported a large population of mature *L. salicaria*, growing in large clumps (Bowen, 1998). The site does not contain *D. verticillatus* or *L. alatum*. Two releases of *Galerucella* beetles were made in Mercer's Glen in 1993 and, by 1997, extremely large beetle populations (estimated over 500 egg masses/m^2, Ontario Program) had caused large reductions in the biomass of *L. salicaria* in this area (Bowen 1998). At the RBG nursery, approximately 1 km from Mercer's Glen, about 200, two-year-old cuttings of *D. verticillatus* were being grown outdoors in small pots in standing water. There were no *L. salicaria* or *L. alatum* plants at this site. The Berry Tract is about 8 km from the nearest *Galerucella* release sites. This site contained a population of several hundred *L. alatum* located in a wet meadow. No *D. verticillatus* and only two plants of *L. salicaria* have been found there. The Double Marsh is located along the southern shore of Cootes Paradise, about 2 km from beetle release sites at Mercer's Glen. At this site, both *L. salicaria* and. *D verticillatus* were found, but there was no *L. alatum* at this site. Populations of *G. calmariensis* could be found on *L. salicaria* all around the shore of Cootes Paradise, but these populations were smaller than those observed at Mercer's Glen (Bowen 1998). Populations of *Galerucella nymphaea* (L.) a native of North America, can also be found in association with purple loosestrife at this site. At the Sunfish Ponds, an area about 0.75 km from two 1993 release sites on Grindstone Creek, *L. salicaria* grew in large clumps around the ponds, but there was no *L. alatum* or *D. verticillatus* growing at this site. Beetle populations had been observed here in 1996, but they were smaller than those found at the release sites (Ontario Program, unpublished data).

Observations of Beetle Activity at the RBG Sites

Observations were made at Mercer's Glen, the Berry Tract and Double Marsh during a site visit on 26 May 1998. On 1 June 1998, estimates of *Galerucella* egg mass density were taken from three, randomly selected 1 m^2 sample plots at Mercer's Glen. On 8 June 1998, five randomly selected 1 m^2 plots containing *L. alatum* plants were sampled for egg masses of *Galerucella* spp. at the Berry Tract. On a weekly basis through June, observations were made during walkabouts at each site to determine the size and distribution of the first generation populations of *Galerucella* at Mercer's Glen, Double Marsh and the Berry Tract.

For the second generation of the beetles, five randomly selected 1 m^2 plots were established on each of: i) *L. salicaria* at Double Marsh; ii) *D. verticillatus* at Double Marsh; iii) *L. alatum* at Berry Tract, and iv) *L. salicaria* at Sunfish Ponds. The number of egg masses of *Galerucella* per plot was counted, and the presence of larval or adult *Galerucella* was noted on a weekly basis from 29 June to 10 August 1998.

Results

Mercer's Glen

On 26 May 1998, the plants of *L. salicaria* were small (under 1 m), but the foliage already had been damaged heavily by feeding adult *Galerucella*. Very few adults were observed in the area, however every plant had a large number of egg masses and most plants had first- to second-instar larvae systematically defoliating the leaves at the top of the shoots.

The mean number of egg masses, 643.0 ± 332.4 (SD) per m^2, counted in three randomly sampled 1 m^2 plots on 1 June 1998, was the highest value recorded at a release site in Ontario (Ontario Program, unpublished data). There were many larvae feeding on the plants, and a number of these larvae appeared to be large enough to pupate.

By the middle of June, all of the purple loosestrife plants in Mercer's Glen were totally defoliated — even the outer layers of the stalks had been chewed away by the beetle larvae. Because no *L. salicaria* was available for oviposition after early to mid-June at Mercer's Glen, monitoring of egg mass abundance of the second beetle generation on *L. salicaria* was moved to the Sunfish Ponds site.

The RBG Nursery

There were approximately 200 plants of *D. verticillatus* at the nursery when observations were made on 26 May 1998. The two-year-old cuttings were under 20 cm in height and had 3–10 leaves per plant. Feeding damage was observed on fewer than 10% of the cuttings, but these plants were heavily damaged, and the foliar shot-hole feeding was consistent with that inflicted by adult *Galerucella*. A few plants had hosted rather large numbers of beetles (>20 per plant, Lyall Rudderham, pers. comm.). Twenty adult insects, collected while feeding on these plants on 19 May, were identified as *G. calmariensis* (Catherine Salole, pers. comm.; specimens in the University of Guelph collection). Several egg masses, thought to be of *G. calmariensis*, were found on the stalks of two of the cuttings that had been fed upon by the beetles.

After feeding had been detected on 19 May, the plants were treated with a mixture of diatomaceous earth and permethrin (Lyall Rudderham, pers. comm.). As of 26 May, there was no evidence of beetle activity on the plants following this treatment.

Through the month of June, two adult *G. calmariensis* were removed from *D. verticillatus* at the nursery. No *Galerucella* egg masses or feeding were observed on the plants through this time period.

The Berry Tract

This site contained the nearest population of *L. alatum* to the established populations of imported *Galerucella*, and it was monitored on 26 May 1998. Several hundred plants of *L. alatum*, approximately 30–50 cm in height, grew in clumps of about 2–8 shoots per clump. Approximately 50 clumps of *L. alatum* were inspected, and on three or four of the plants, shot-hole feeding damage, characteristic of *Galerucella* adults, was observed. On two plants, we found egg masses, believed to be those of *G. calmariensis*.

A shoot of *L. alatum* containing three small egg masses was brought back to the laboratory for rearing. Fourteen eggs were counted in the egg masses. The shoot was held in a closed plastic container, suspended over water on a platform of chicken wire, with the cut stem placed in the water to prevent desiccation. After the eggs hatched and larvae began to grow, fresh shoots of *L. alatum* were placed in the box to nourish them. When eight, full-grown larvae were ready to pupate, a 9 cm petri dish containing a small amount of potting soil was placed on the frame under the shoots. An unknown number of larvae entered the soil to pupate, and four adult beetles, later identified as *G. calmariensis*, were reared successfully from the shoots of *L. alatum* (Catherine Salole, pers. comm.; specimens in the University of Guelph collection).

In sampling done on *L. alatum* at the Berry Tract (10 June), two of the five, 1 m^2 plots contained egg masses of *G. calmariensis* and a total of seven egg masses were counted (1.4 ± 2.2 [SD] masses per m^2). One larval *Galerucella* was seen and there was evidence of slight adult (shot-hole) and larval feeding (shoot-tip damage, windowing of leaves) on a few plants. In two further visits to this site (17, 24 June) no beetle life stage or new feeding damage was observed on *L. alatum*, including the plants on which activity had been recorded on 8 June.

Double Marsh

At this site, the plants of *L. salicaria* and *D. verticillatus* grew relatively close to each other (0.5 to 20 m apart) as emergent shoots in about 0.5–1 m of water. *L. salicaria* grew in clumps of about 20–40 shoots, with foliage standing up to 0.5 m above the water. Clumps of *D. verticillatus* were smaller, consisting of 1–5 shoots and standing about 0.3 m out of the water.

About 20 specimens of each of *D. verticillatus* and *L. salicaria* were examined on 26 May, and adult *G. calmariensis* were found sitting on both plant species. Feeding damage by adult *Galerucella* and egg masses were found on plants of *L. salicaria*; however, neither larval or adult feeding damage was observed on *D. verticillatus*.

During weekly monitoring of the same plants done through June, *L. salicaria* showed moderate to heavy feeding damage by adults and larvae of *G. calmariensis*. Some plants were starting to bloom, but many were too damaged to do so. Plants of *D. verticillatus* were completely free of adult and larval feeding damage throughout the month of June, although four adult *G. calmariensis* and a single egg mass were observed on them.

Monitoring of Second Generation *G. calmariensis* Populations — July–August, 1998

Only *L. salicaria* was attacked by the second generation of *Galerucella*, with no ovipositions being recorded on *L. alatum* at the Berry Tract or on *D. verticillatus* at Double Marsh (Table I). At the Sunfish Ponds site, an average of about 882 egg masses per m^2 were recorded on *L. salicaria* in the first week of monitoring (Table I). These plants were quickly defoliated and became unsuitable for oviposition for the rest of the monitoring period.

The plots of *L. salicaria* at Double Marsh harbored moderate numbers of egg masses throughout the sampling period, yet no egg masses, larvae or adult *Galerucella* were found on *D. verticillatus* at any time (Table I). Incidentally, no individuals of *G. pusilla* were found on either non-target species at any point in our investigations in 1998.

TABLE I. Mean numbers (± SD, n = 5) of egg masses per m^2 found for the second-generation, imported *Galerucella* spp. on *Lythrum salicaria*, *D. verticillatus* and *L. alatum* at several locations around the Royal Botanical Gardens, Burlington, Ontario. *Lythrum alatum* was not present at Double Marsh or Sunfish Ponds, *D. verticillatus* was absent from Sunfish Ponds and the Berry Tract, and only two plants of *L. salicaria* were detected at the Berry Tract.

Date (1998)	Double Marsh *L. salicaria*	Double Marsh *D. verticillatus*	Sunfish Ponds *L. salicaria*	Berry Tract *L. alatum*
June 29	8.6 ± 11.6	0	882.4 ± 489.8	0
July 6	35.4 ± 66.4	0	nd *	0
July 13	42.4 ± 79.3	0	nd	0
July 20	57.2 ± 101.1	0	nd	0
July 27	57.8 ± 47.2	0	nd	0
August 3	54.8 ± 100.6	0	nd	0
August 10	21.5 ± 32.6	0	nd	0

* nd = no data collected; plants unsuitable for oviposition

Discussion

In pre-release laboratory feeding trials in which the insects did not have access to *L. salicaria* (no choice tests), adult *G. calmariensis* were found to feed and oviposit on both *D. verticillatus* and *L. alatum* (Kok et al. 1992; Blossey et al. 1994b). *Lythrum alatum*, and two species of *Ammania* (*A. auriculata* Willd. and *A. latifolia* L.) were the only plants, other than *L. salicaria*, on which *G.*

calmariensis could complete larval development (Kok et al. 1992; Blossey et al. 1994b). Few adults were produced on these species, relative to the numbers reared from *L. salicaria* (Kok et al. 1992; Blossey et al. 1994b). Referring to *Galerucella*, Kok et al. (1992) concluded that: "both species of beetles are highly host specific and should not be a threat to non-target plants with the exception of *L. alatum*.". However, Blossey et al. (1994b) cautioned that it was unclear whether laboratory tests would have predictive power for field releases.

Our observations of activity by *Galerucella* in actual field releases closely parallel those recorded during host-specificity testing of the beetles prior to their release in North America (Kok et al. 1992; Blossey et al. 1994b). Adults of *G. calmariensis* fed and oviposited upon both *D. verticillatus* and *L. alatum* at RBG, although the populations of beetles found on these plants were several orders of magnitude smaller than those observed on *L. salicaria*. Four individuals of *G. calmariensis* completed development on *L. alatum* in the laboratory, but no late-instar larvae were ever observed on either non-target plant species in the field. Both plant species were located inside an area where populations of *Galerucella* could be found attacking virtually every purple loosestrife plant. We believe that the testing procedures used to determine the host range of *G. calmariensis* (Kok et al. 1992; Blossey et al. 1994b), provided accurate predictions of their performance in field releases.

We speculate that the situation that promoted non-target feeding by *G. calmariensis* on *D. verticillatus* at the nursery was, in essence, a "no-choice trial" for these insects. The Mercer's Glen release sites harbored extremely large populations of *Galerucella* in 1997 (estimated 500 egg masses/m^2). In July 1997, we observed mass emigrations of newly emerged, second generation adults, believed to be due to a scarcity of available foliage of purple loosestrife there (Ontario Program, unpublished data). In a number of successful biological control programs, "waves" of populations of biocontrol agents have been observed to move from their release sites to exploit their host species elsewhere (Kovalev 1989). The rapid rate with which *Galerucella* invaded all purple loosestrife populations around the RBG properties is thought to have resulted from waves of hungry beetles that migrated from areas where the purple loosestrife had been totally utilized.

Based on samples taken at Mercer's Glen on 1 June 1998 (over 600 egg masses/m^2), we concluded that many beetle adults had over-wintered at this site. We speculate that, in several areas where they over-wintered (such as Mercer's Glen), large populations of emerging adult beetles quickly utilized all available *L. salicaria*. Dispersing from these areas to find undamaged host plants, some adults encountered *D. verticillatus* in the nursery. For the beetles, these plants were their only (short-term) choice for feeding, and some adult *G. calmariensis* did attack a few of them.

At Double Marsh, *Galerucella* populations were much lower than those observed at Mercer's Glen. Plants of *L. salicaria* were less damaged and were healthy enough that adult *G. calmariensis* had a choice of these plants or of *D. verticillatus* on which to feed and oviposit throughout the season. Faced with this choice, *G. calmariensis* did not utilize the *D. verticillatus* plants at Double Marsh.

Use of *L. alatum* at Berry Tract was minimal, compared with that observed on *L. salicaria* plants around the RBG properties. The scarcity of purple loosestrife plants around the Berry Tract did not allow for estimates of the size of the populations of *G. calmariensis* in the immediate area. Nonetheless, the numbers of damaged plants and egg masses found on *L. alatum*, relative to those found on *L. salicaria* growing elsewhere at RBG, support the assertion (from host range testing) that *L. alatum* is not a favoured host for *G. calmariensis*.

We believe that non-target feeding by *G. calmariensis* represents a short-term "spill-over" effect. Once populations of *L. salicaria* are reduced by *Galerucella* species, beetle populations would collapse in response to the new carrying capacity of their principal host species, *L. salicaria*. We feel that the smaller beetle populations would pose no long-term threat to non-target species.

Other weed biological control programs have experienced similar short-term incidences of attack with no long-term effects on the non-target species (McFadyen 1998). Despite this history, two different outcomes have been suggested for the interactions between a relatively rare plant species and a herbivore that is found in high densities on its usual host.

Wan and Harris (1997) suggest that the probability of a host shift can be calculated by conducting several comparisons of relative feeding, oviposition and larval development between the intended host species and a non-target species. If the non-target host species is less acceptable or suitable than the intended host across several behavioral and physiological tests, then each "disadvantage" would serve to prevent the host shift. The multiplicative product of the test results would represent the relative probability of the natural enemy establishing a population on the non-target plant, compared to the target species (Wan and Harris 1997). For the *Galerucella* beetles, for which all parameters of relative suitability strongly favoured purple loosestrife (Kok et al. 1992; Blossey et al. 1994b), the relative utilization rates suggest that the probability of a host shift to either *L. alatum* or *D. verticillatus* is very low.

Unfortunately, another less desirable outcome of these interactions has been postulated (Howarth 1991; Strong 1997). In outbreak situations, a proportion of a large population of natural enemies attacking a targeted plant species can "spill over" onto a non-target species. The non-target species may or may not be "favoured" by the herbivores; in fact, it may not even be a suitable species for a long-term host shift. However, it is possible that a relatively small population of the non-target species may not be able to withstand even "incidental" feeding by a large number of herbivores. The authors concluded that local extinctions of rare, non-target species could occur as a side effect of a successful biological control program against another species (Howarth 1991; Strong 1997).

Critics of classical biological control have lamented the lack of follow-up ecological studies of the long-term impacts of these programs (Simberloff and Stiling 1996). We believe that *Galerucella* introductions at RBG afford an excellent opportunity to conduct such studies. In future research, we hope to provide data to help examine the divergent hypotheses about host shifts and impact of weed biological control agents on non-target species.

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LEADER AND SYSTEMIC APPLICATIONS OF NEEM EC FORMULATIONS FOR CONTROL OF WHITE PINE WEEVIL (COLEOPTERA: CURCULIONIDAE) ON JACK PINE AND WHITE PINE

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Abstract

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Neem EC formulations containing azadirachtin were applied to the leaders of jack pine or white pine with a compressed air sprayer at 20 ml/tree to control damage by white pine weevil. Applications of commercial formulations (Azatin, Neemix 4.5) and experimental formulations (PheroTech Inc., Neem International Enterprises Inc.) at 0.02 g azadirachtin/tree in early to mid-June provided 68–82% protection of leaders if applied when 26–63% of the eggs had hatched. Earlier or later applications were not as effective. A lower dosage of 0.01 g azadirachtin/tree provided 37% protection. Leader applications of neem offer a safer alternative to conventional insecticides, and provide a better time period for application compared to standard contact insecticide treatments. Systemic applications of neem EC formulations at 0.05 g azadirachtin/tree in holes at the trunk base resulted in insignificant reductions in leader damage when applied at the start of oviposition.

Introduction

The white pine weevil, *Pissodes strobi* Peck, feeds on several species of pine and spruce in North America. The eggs are laid in chambers, usually one per chamber, underneath the bark of the main terminal stem of the tree (leader) and each chamber is sealed with a frass plug (Wallace and Sullivan 1985). Up to 200 eggs may be laid on a leader and the eggs hatch in about two weeks. Larvae tunnel downwards in the phloem eventually forming a "feeding ring" around the circumference of the leader, that effectively girdles and kills the leader (Wallace and Sullivan 1985). Leader damage often results in poor stem form, reduced height growth, and when intra- or inter-specific competition is severe, attacked trees become suppressed and may eventually die (Alfaro 1994).

There has been a long history of controlling the weevil, especially by silvicultural practices and insecticides (de Groot 1985; Stiell 1985; de Groot and Helson 1994). Silvicultural techniques such as underplanting or close spacing of trees are generally the preferred choices; however, these techniques are not always practical or desirable in some forestry situations. Recent studies have shown that applications of either permethrin or methoxychlor to individual leaders of jack pine, *Pinus banksiana* Lamb, were effective in suppressing weevil populations below a 5% leader damage threshold (de Groot and Helson 1993; de Groot et al. 1995). However, one of the limiting factors in the application of these insecticides is the need for precise early timing.

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Neem is a botanical insecticide containing the primary active ingredient, azadirachtin, derived from extracts of the seed kernels of the neem tree, *Azadirachta indica* A. Juss. It shows considerable promise as a safe alternative for the control of a number of forest insects (Helson 1992; Schmutterer 1995). Neem exhibits growth inhibiting activity and antifeedant effects on insect larvae (Schmutterer 1995) and has been shown to have systemic activity against forest insects (Marion et al. 1990; Naumann et al. 1994; Lyons et al. 1996; Wanner et al. 1997). Herein we report the results of a series of field trials to determine the effectiveness of neem for control of the white pine weevil. We tested neem by direct application to the surface of terminal shoots of eastern white pine, *P. strobus* L., and jack pine. Our hypothesis was that neem would be absorbed through the bark to the feeding sites of the larvae in the cambial layer. Here the larvae would discontinue feeding either as a result of behavioral deterrence or physiological effects following ingestion. Foliar applications of conventional systemic insecticides have been effective against weevil larvae in the leader (Johnson and Zingg 1966; Bradbury 1986). If neem was effective, it would not only alleviate the need for the precise, early timing currently required with contact insecticides (de Groot and Helson 1993; de Groot et al. 1995) but also could provide an environmentally sound alternative (Schmutterer 1995). We also examined the efficacy of neem injected directly into the base of trunks of white pine.

Materials and methods

Leader application. Three field trials were conducted to determine the effectiveness of neem applied directly to the leaders. In all trials, trees were sprayed individually with a Solo Port 40123® backpack sprayer calibrated to deliver 600 ml/minute. The spray was applied at the rate of 20 ml/ leader by spraying opposite sides of the leader with two, 1-second bursts to ensure total coverage. Approximately 50 cm of the terminal stem was treated.

The first trial was conducted in 1994 in a 6-year-old jack pine plantation located in Cuthbertson township north of Sault Ste. Marie, Ontario. Trees were about 2.4 m tall and had suffered about 19% leader damage the previous year. To evaluate the optimal timing for neem treatments, a randomized complete block design with three blocks of six plots of 50 trees was used. In each block, plots were randomly assigned one of the six application timings. The plots were separated by 100 m or more in order to avoid contamination from other treatments. Starting 28 April, 20 jack pine leaders from trees near the blocks were collected at least weekly and on the day of insecticide treatment. These leaders were dissected to determine the number of unhatched eggs and larvae present. The first treatment was made when adults were first found feeding (9 May) and the second soon after the first eggs were deposited in the leaders (18 May). The third, fourth and fifth applications were made when the leader samples contained 100% unhatched eggs (25 May), 34% egg hatch (15 June) and 58% egg hatch (22 June), respectively. In each block, one plot was left as an untreated control. An experimental EC formulation of neem (PheroTech Inc., Delta, British Columbia) containing 1.75% azadirachtin was diluted in water to give a concentration of 0.1% azadirachtin (equivalent to 0.02 g AI/tree or 50 g AI/ha at 2500 trees/ha). Applications were carried out between 0930 and 1100 h. In a separate experiment, another formulation of neem, Azatin® (3% azadirachtin, EC, Agridyne, Salt Lake City, Utah) was applied to three additional, nearby plots of 50 trees on 15 June at 0.02 g AI/tree. The three plots of untreated trees from the timing study were used as controls.

The second trial was conducted in 1995 in two white pine plantations south of Owen Sound, Ontario.The objective of this trial was to evaluate the efficacy of leader applications of neem on white pine. Plantation 1 was established in 1988 in Artemestia township. Trees were planted at a density of about 2200 stems/ha and were 1.5 to 3.5 m tall. Plantation 2 was located in Sullivan township and planted in 1986. Trees were planted at a density of 2800 stems/ha and were 1.5 to 5 m tall. Plantation 1 was divided into six plots of 50 trees and plantation 2 was divided into five plots of 50 trees, both with 10 m between plots. Ten leaders from nearby trees were collected weekly from each plantation to monitor egg hatch. On 8 June, two randomly selected plots in each plantation were treated when leader samples indicated that 63% of the eggs had hatched. On 22 June, two more plots from plantation 1 and one plot from plantation 2 were treated at 87% egg hatch to determine if significant protection could be achieved after most of the eggs had hatched. Spray applications were done as in 1994 with the PheroTech formulation. Two, 50-tree plots in each plantation were left as untreated controls. Data for the two plantations have been combined for analysis.

The third trial was carried out in a white pine plantation near Paisley, Ontario. On 5 June, 1996, Neemix® 4.5 (a commercial EC formulation from ThermoTrilogy, Columbia, Maryland, USA) containing 4.5% azadirachtin was applied to the leaders of three groups of 50 trees at each of two dosages: 0.01 and 0.02 g azadirachtin/leader. At the time of treatment, leader samples indicated 26% egg hatch. Three groups of 50 trees were left as untreated controls.

Trunk injection. In 1996, 300, 3–4 m tall trees were selected for treatment within a white pine plantation near Markdale, Ontario. One hundred trees each were randomly assigned for trunk injection, leader treatment or untreated controls. For the trunk injection treatment, two holes, 2 cm deep and 1 cm in diameter, were drilled at a 60° angle on opposite sides near the base of each tree on 15 May 1996, at the beginning of weevil oviposition. Into each hole, 1.25 ml of an experimental EC formulation (2% azadirachtin, Neem International Enterprises Inc. Surrey, British Columbia) was pipetted for a total of 0.05 g azadirachtin/tree. Leader treatments were made on 11 June with this formulation at 0.02 g/leader when leader samples indicated 36% egg hatch.

Assessment of efficacy and data analysis. In late August or early September, when weevil larvae had completed feeding, each treated and untreated tree was examined to determine if the leader was alive or dead. For each trial, the proportion of leaders alive and dead was analyzed by contingency table analysis using the Pearson's χ^2 as the test statistic at $\alpha = 0.05$ (SYSTAT 7.0, SPSS Chicago).

Results

Leader application. The results are summarized in Table I. In the first trial, leader damage on jack pine was 11, 7, 8, 3, 5 and 19% for the five different application timings and the untreated control, respectively. The first application was not significantly different from the control ($\chi^2 = 3.2$, df = 1, $P > 0.05$). The subsequent treatments all had significantly less leader damage than the untreated control ($\chi^2 > 7.3$, $P < 0.05$). Azatin also resulted in significantly less leader damage (5%) ($\chi^2 = 14.3$, df = 1, $P < 0.01$). In the second trial, leader damage on white pine was 6, 17 and 19% for the early treatment, late treatment and untreated control, respectively. Only the early treatment, when the leaders showed that 63% of the eggs had hatched resulted in significantly lower damage than the untreated control ($\chi^2 = 15.5$, df =1, $P < 0.01$). In the third trial, the 0.02 g azadirachtin/tree treatment resulted in significantly lower leader damage (7%) than the untreated control (27%) ($\chi^2 = 21.6$, df = 1, $P < 0.01$) as did the 0.01 g azadirachtin/tree treatment (17%) ($\chi^2 = 4.4$, df = 1, $P < 0.05$).

Trunk injection. Injection of the azadirachtin did not result in significantly lower damage when compared to the untreated controls. The damage levels were 20% for the treatment and 31% for the untreated controls ($\chi^2 = 3.0$, df = 1, $P = 0.08$). This trial also contained a leader application to provide a direct comparison with the systemic treatment. This treatment resulted in 7% leader

TABLE I. Protection of tree leaders from white pine weevil damage with neem EC formulations.

Species	Year	Formulation	Dosage gAI/tree	Date	Egg hatch (%)	Leader damage (%)	Leader protection (%)[1]
Jack pine	1994	PheroTech	0.02	9 May	0	11	39
				18 May	0	7	61
				25 May	0	8	57
				15 June	34	3	82
				22 June	58	5	71
		Azatin	0.02	15 June	34	5	75
		Untreated				19	
White pine	1995	PheroTech	0.02	8 June	63	6	68
				22 June	87	17	12
		Untreated				19	
White pine	1996	Neemix	0.01	5 June	26	17	37
			0.02	5 June	26	7	74
		Untreated				27	
		Neem Int.	0.02	11 June	36	7	77
		Untreated				31	

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[1] % leader protection = 100 × (Damaged untreated leaders – Damaged treated leaders) ÷ Damaged untreated leaders

damage, which was significantly different from the systemic treatment ($\chi^2 = 6.2$, df = 1, $P < 0.05$), and similar to other comparable leader applications to white pine (Table I).

Discussion

Direct application of neem formulations to the leaders of white or jack pine at 0.02 g azadirachtin/tree (0.1%) was effective for control of white pine weevil when the leaders contained eggs and less than 63% of the eggs had hatched. Applications made before or after this time were not as effective. Based on the egg hatching periods in our trials, a spray window of up to one month is possible. This would compare with 2–3 weeks for applications of the conventional insecticides, permethrin and methoxychlor, made soon after the first adults are observed in the spring and before eggs are deposited (de Groot and Helson 1993; de Groot et al. 1995). Later applications are also preferable because roads to sites are accessible (snow-free and dried out) and weather conditions are more reliable and milder. The best leader protection (74–82%) on both tree species was obtained when 26–36% of the eggs had hatched. No important differences among formulations were noted.

The results with neem were similar to leader applications of the systemic insecticide oxydemeton-methyl, although it also provided protection in an early treatment (Bradbury 1986). This difference could be due to the higher concentration of oxydemeton-methyl used (1%), residual activity or its contact action against adults or all of these. Neem has no demonstrated, direct toxic effects to adults (Helson unpublished).

In a recently published study in western Canada, leader applications of neem seed extract to Sitka spruce, *Picea sitchensis* (Bong.) Carr, did not significantly affect weevil populations in leaders although leader damage was not reported (Naumann et al. 1996). They sprayed the leader with 100 ppm AI to runoff. In our study, we sprayed each leader with 20 ml of a 1000 ppm solution. Protection of the leader appears to be dependent on the concentration applied because a dosage of 0.01 g AI/tree (500 ppm) provided 37% leader protection compared to 74% at 0.02 g AI/tree (Table I). Although the tree species and climatic conditions differ between the two studies, differences in quantities of neem applied to the leaders could explain the discrepancy in effectiveness. Naumann et al. (1996) sprayed leaders at two different times, one week and three weeks after oviposition. The early spray had no effect but the later spray had consistently lower numbers of adult exit holes, pupal cocoons and larvae compared to the control. This later timing is similar to the optimal timing for leader sprays in our study.

The effectiveness of applications of neem to the leader when eggs and larvae are present underneath the bark suggests that it absorbed into the phloem region. Sundaram et al. (1997) has shown that azadirachtin can penetrate the basal bark of white spruce and translocate to the needles in small amounts. Additional studies will be required to determine how azadirachtin enters and moves within a leader after external application. If neem is being absorbed into the phloem through the bark on the leader, application of concentrated formulations at ultra-low volumes or special formulations adhering to bark surfaces with high penetrating properties might increase the amount of neem reaching weevil larvae.

Stem injections of azadirachtin were unexpectedly unsuccessful because such treatments have been effective for phloem-feeding bark beetles in lodgepole pine, *P. contorta* Douglas var. *latifolia* Engelmann (Naumann et al. 1994), and for folivorous lepidoptera on white spruce, *P. glauca* (Moench) Voss, and black spruce, *P. mariana* (Mill.) B.S.P. (Wanner et al. 1997). In fact, a systemic treatment of neem to similarly sized red pine, *P. resinosa* Ait., at the same dosage with the same formulation and using the same technique provided excellent control of pine false webworm, a folivorous sawfly (Lyons et al. 1996). This suggests that either white pine weevil larvae are less susceptible or neem is being translocated to the needles more efficiently than to the phloem. Sundaram et al. (1997) have shown that azadirachtin is translocated very efficiently to the needles after similar systemic injections of small white spruce trees.

The timing of the systemic treatment may not have been ideal for azadirachtin to reach the phloem during the active growth period of pine. A very early spring treatment or late fall treatment might improve the distribution to the phloem. Naumann et al. (1996) also did not obtain much effect with similar systemic applications of neem to Engelmann spruce, *P. engelmannii* Parry, and Sitka spruce, although the number of emergence holes/leader in Sitka spruce was greatly reduced. As with leader clipping, successive systemic applications of neem for 2-3 years could be evaluated for population suppression. Fraser and Heppner (1993) found that systemic applications of oxydemeton-methyl and acephate to Sitka spruce were very effective in protecting trees from white pine weevil attack. However the dosages used were 20 or more times higher than neem for comparably sized trees. Higher dosages of neem for systemic applications may not be practical because neem formulations have relatively low concentrations of azadirachtin and at present costs, would not be economical.

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EFFECTIVENESS OF NEEM- AND DIFLUBENZURON-BASED INSECTICIDES FOR CONTROL OF THE PINE FALSE WEBWORM, *ACANTHOLYDA ERYTHROCEPHALA* (L.) (HYMENOPTERA: PAMPHILIIDAE)

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Abstract

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The effectiveness of two emulsifiable concentrate formulations of neem seed extracts containing azadirachtin, Azatin® EC and Neem EC, and of a wettable powder formulation of diflubenzuron, Dimilin® WP, was evaluated in the laboratory and field for control of the pine false webworm, *Acantholyda erythrocephala* (L.) (Hymenoptera: Pamphiliidae). In laboratory bioassays, no effects of treatments on eggs of pine false webworm were detected at maximum application rates of Azatin EC at 50.0 g AI/ha, Neem EC at 5.0 g AI/ha or Dimilin WP at 25.0 g AI/ha. All of these products were highly toxic to pine false webworm larvae in laboratory bioassays at application rates above 1 g AI/ha. In field trials, Dimilin WP at 35 or 70 g AI/ha was very effective, providing population reductions greater than 96% and foliage protection above 87%. The two EC formulations of neem seed extracts were also effective in mistblower applications at 50 g AI/ha in 4 trials over three years. Population reductions ranged from 74–93% and protection of one-year-old and current-year foliage ranged from 37–85% and 72–100%, respectively. Neem- and diflubenzuron-based insecticides are both suitable candidates for pine false webworm control.

Introduction

The pine false webworm, *Acantholyda erythrocephala* (L.), an introduced pamphiliid sawfly of Palearctic origin, has become a serious defoliator of pines, *Pinus* spp., in Ontario and New York (Lyons 1995). The gregarious larvae of this sawfly feed from within webs, constructed of silk, frass, exuviae and uneaten needles, that enclose the branches of the host trees (Lyons 1994). A chemical control strategy has been developed for the species using conventional synthetic insecticides (Lyons et al. 1993) but no control products are currently registered for use against this species in Canada or the United States. Dissatisfaction with conventional insecticides has lead to the search for effective and safe alternatives for use in forestry applications.

Botanical insecticides formulated from neem seed extracts containing azadirachtin (neem) have shown considerable promise as safe alternatives to conventional synthetic insecticides for controlling forest insect pests (Helson 1992; Schmutterer 1995). Azadirachtin is the most active constituent in extracts from the seeds of the neem tree, *Azadirachta indica* A. Juss. (Meliaceae), although other compounds in neem have insecticidal properties (Schmutterer 1990). The mode of action of azadirachtin is varied and includes direct toxicity, growth and developmental inhibition, and feeding, oviposition and settling deterrence (Schmutterer 1990). Neem formulations were very active on the spruce budworm, *Choristoneura fumiferana* (Clemens), under laboratory conditions (Thomas et al. 1992) and retarded their development and protected foliage in white spruce, *Picea glauca* (Moench) Voss. seed orchards (Wanner and Kostyk 1995). Under laboratory conditions, neem seed extracts reduced gypsy moth, *Lymantria dispar* (L.) numbers and may have synergistically enhanced the activity of its virus (Shapiro et al. 1994). The systemic property of neem formulations was exploited by Naumann et al. (1994) to mitigate populations of mountain pine beetle larvae, *Dendroctonus ponderosae* Hopkins and by Wanner et al. (1997) to protect foliage of spruces from feeding by spruce budworm.

There is evidence that sawflies are particularly susceptible to this product. The birch leafminer, *Fenusa pusilla* (Lepeletier), has been controlled using both foliar (Larew et al. 1987) and systemic (Marion et al. 1990) applications of neem seed extracts. Schmutterer (1985) reported good results using neem against the spruce sawfly, *Pristiphora abietina* (Christ), on young spruce trees, where feeding damage to treated shoots was slight after application rates of 100 and 500 ppm/litre. Finally, in laboratory bioassays, Azatin® EC was very toxic to the larvae of six diprionid sawfly species (Helson et al. in press).

Another group of chemicals that are reported to be safe alternatives to conventional neurotoxic insecticides are the benzoylphenyl ureas which act as chitin synthesis inhibitors in larval insects and thus interfere with ecdysis (Retnakaran and Wright 1987). One such compound, diflubenzuron, is the active ingredient in the commercial formulation, Dimilin®. Laboratory evidence indicates that diflubenzuron is effective at controlling diprionid and tenthredinid sawflies feeding on conifers (Valovage and Kulman 1978a,b,c). Based on greenhouse trials, Fogal (1977) found that diflubenzuron caused substantial larval mortality of *Diprion similis* (Hartig) at the time of moult and, if applied prior to egg hatch, would provide effective foliage protection for white pine, *P. strobus* L. Dimilin has also been successfully used to control the pine false webworm in a Scots pine, *P. sylvestris* L., plantation in Bulgaria (Tsankov et al. 1989).

The objective of this study was to evaluate the laboratory and field efficacy of neem and diflubenzuron formulations for control of the pine false webworm on red pine, *P. resinosa* Ait. The systemic activity of neem against the pine false webworm has been reported previously (Lyons et al. 1996).

Materials and Methods

Laboratory Bioassays. Eggs used in the laboratory bioassays of neem and diflubenzuron were reared from adults collected as pronymphs and pupae in fall and spring, respectively, from a red pine plantation near Sprucedale, Ontario. These were supplemented with eggs from gravid females collected from red pine near Sprucedale, as well as from mugho pine, *P. mugo* Turra var. *mughus* Zenari, in Sault Ste. Marie, Ontario.

Adult pairs or mated females were placed into rearing cages containing red pine branch tips (see Lyons et al. 1993) collected from a plantation near Sault Ste. Marie. All rearings and bioassays were conducted in a controlled environment room at 22–23 °C, 70–80% relative humidity and a 16L:8D photoperiod. Each day, branch tips with newly deposited eggs were removed from the cages and replaced with fresh branch tips. Females were allowed to oviposit until they were spent. The cut ends of egg-bearing branches were surface-sterilized and placed in 200 ml glass olive jars containing distilled water. The number of eggs laid on each branch was recorded.

Six days after oviposition, the number of swollen (viable) eggs was recorded, the basal ends of the branch tips were clipped to expose fresh wood and the water in the jars was changed. The branches were divided into groups such that similar numbers of eggs were in the daily treatment and control groups. On the same day, branches in treated groups were sprayed with aqueous mixtures of one of the following insecticide formulations: 1) Azatin® EC (AgriDyne Technologies Inc., Salt Lake City, UT; 3% azadirachtin); 2) Neem EC (PheroTech Inc., Delta BC; 1.75% azadirachtin);

or 3) Dimilin® WP-25 (Duphar B.V., Weesp, Holland; 25% diflubenzuron). In bioassays conducted in 1992, branches were treated with Azatin EC at application rates of 2.5, 5.0, 10.0, 15.0, 20.0, 25.0 and 50.0 g active ingredient AI/ha and Dimilin WP at application rates of 3.125, 6.25, 12.5 and 25.0 g AI/ha. Bioassays in 1994 were conducted using the Neem EC and Dimilin WP formulations at 0.008, 0.04, 0.2, 1.0 and 5.0 g AI/ha. As a comparison, Azatin EC was applied at 1.0 g AI/ha to a third group of branches. Control branches containing eggs were sprayed with water in each year. Rhodamine B red dye (0.1%) and Dowanol® TPM (1.0%) (Dow Elanco Canada Inc., Newmarket, ON) were added to all treatment and control sprays. Dowanol enhances spray atomization and reduces evaporation of the water. All branches were treated in a spray chamber using a spinning-disc, low-volume atomizer (for a description of the spray chamber see Lyons et al. 1993).

Twelve days after oviposition the number of hatched eggs on each branch was recorded. The branches were clipped again and returned to the jars containing fresh water. Eighteen days after oviposition (12 days after treatment) the number of live larvae found on each branch was recorded. The number of dead eggs was calculated as the number of viable eggs at six days after oviposition minus the number of hatched eggs at 12 days after oviposition. The number of dead larvae was calculated from the number of hatched eggs minus the number of live larvae at 18 days after oviposition. For analysis, the numbers of live and dead insects were pooled for all branches treated with the same formulation at the same concentration. For both eggs and larvae, corrected mortality (CM) was calculated using Henderson and Tilton's (1955) modification of Abbott's formula:

$$CM\,(\%) = \left(1 - \left(\frac{t_2 \times c_1}{t_1 \times c_2}\right)\right) \times 100$$

where t_1 = the number of live treated insects before treatment, t_2 = the number of live treated insects after treatment, c_1 = the number of live control insects before treatment and c_2 = the number of live control insects after treatment. For corrected mortality values greater than 0, the number of living and dead insects was compared between the treatments and the controls by χ^2 analysis using procedure FREQ (SAS Institute 1990). For bioassays conducted in 1994, larval mortality resulting from applications of Neem EC and Dimilin WP were compared by probit analysis using POLO-PC (LeOra Software 1987).

Field Trials. To determine the efficacy of diflubenzuron and neem under field conditions, rows of red pine trees in a plantation near Sprucedale, Ontario were sprayed in 1991, 1993, 1994 and 1995 with these products (for a description of the plantation see Lyons et al. 1993). The number of trees per treatment was 40 in 1991 and 30 in all other years. Treated rows had a minimum of nine rows of trees between them. An upper and lower branch tip, randomly chosen by cardinal direction, was selected on each treatment tree and marked with flagging tape. The number of eggs on each marked branch tip was counted within a few days prior to treatment. If a marked branch tip contained more than 20 eggs, the number of eggs was culled down until there were 20 eggs or fewer per branch tip. In all years, a sample of eggs was collected from throughout the plantation to determine percentage hatch at or near the time of spray application. These samples were collected 31 May 1991, 16 June 1993, 15 June 1994 and 9 June 1995.

Trees were sprayed in all years using a Solo®Port 423 motorized backpack mistblower equipped with a standard nozzle. On 1 June 1991, treatment trees were sprayed with Dimilin WP-25 at 70 g AI/ha, the highest rate registered for gypsy moth control. On 16 June 1993, treatment trees were sprayed with Dimilin WP-25 at 35 g AI/ha, the lowest rate for gypsy moth control. Azatin EC was applied at an experimental rate of 50 g AI/ha on the same date. On 16 June 1994, the two azadirachtin-based formulations, Azatin EC and Neem EC, were compared at dosages of 50 and 200 g AI/ha each. On 15 June 1995, Neem EC was tested again at 50 g AI/ha. Each year a row of trees was sprayed with water to serve as a control for population reduction comparisons. In all years, treatments were randomly assigned to the selected rows.

Approximately two weeks following treatment, population reduction was assessed by destructively sampling the marked branch tips and counting the number of living larvae. Larvae were sampled 17–19 June 1991, 7 July 1993, 5 July 1994 and 28 June 1995. Population reduction (PR) was determined from the following:

$$PR\,(\%) = \left(1 - \left(\frac{larvae}{eggs}\right)\right) \times 100$$

where larvae = the number of larvae on branch tips after treatment and eggs = the number of eggs on branch tips prior to treatment (Lyons et al. 1993). Eggs and larvae lost from the branches, due to other mortality factors or completion of development, should be equally distributed on both treated and control branches. Mean population reductions were calculated for upper and lower branches, and for pooled upper and lower branches for each treatment. Mean population reductions were compared between upper and lower branches within a treatment using procedure TTEST (SAS Institute 1990). Population reductions for pooled branches in each treatment were compared, by year, after arcsine square-root transformation of the data, by ANOVA followed by Tukey's multiple range test using procedure GLM (SAS Institute 1990).

Defoliation estimates were made after larval drop was completed. These estimates were made on 4–5 July 1991, 10 August 1993, 10 August 1994 and 17 August 1995. Both one-year-old foliage and current-year's foliage were assessed for damage. Defoliation was estimated subjectively, in increments of 10%, by two observers in all treatment rows and in adjacent upwind untreated rows. Mean defoliation of treated trees and upwind untreated trees were compared using *t*-tests after arcsine square-root transformation of the data using procedure TTEST (SAS Institute 1990). Corrected foliage protection (FP) for current-year and one-year-old foliage was calculated from the following:

$$FP\,(\%) = \left(\frac{u - t}{u}\right) \times 100$$

where u = the mean percentage defoliation of upwind untreated trees and t = the mean percentage defoliation of treated trees (Lyons et al. 1993).

Heights of treatment and control trees were measured in all years except 1993. Within a year, mean tree heights for each treatment were compared by ANOVA followed by Tukey's studentized range test using procedure GLM (SAS Institute 1990).

Results and Discussion

Laboratory Bioassays. None of the three products tested had any appreciable effects on survival of the eggs of the pine false webworm under laboratory conditions (Tables I and II). Although there were occasional small mortality values that were significantly different from the controls at some concentrations of the three products, at the maximum concentrations, corrected egg mortality was not significantly different from the controls. The branches were all treated six days after eggs had been deposited. At the experimental temperatures, the eggs had undergone most of their development

TABLE I. Effects of neem and diflubenzuron formulations, applied to red pine branches in the laboratory six days after oviposition, on egg hatch of the pine false webworm in 1992.

Product	Dosage (g AI/ha)	Number of eggs: Control Alive	Control Dead	Treatment Alive	Treatment Dead	Corrected mortality*	χ^2	P[†]
Azatin EC	2.5	42	5	49	11	8.6	1.22	0.268
	5.0	284	43	285	35	0.0	-	-
	10.0	300	44	284	62	5.9	3.49	0.062
	15.0	251	22	236	42	7.7	6.67	0.010
	20.0	53	3	41	16	24.0	10.42	0.001
	25.0	273	13	289	14	0.0	-	-
	50.0	235	11	232	3	0.0	-	-
Dimilin WP	3.125	190	43	191	41	0.0	-	-
	6.25	269	30	292	30	0.0	-	-
	12.5	425	47	416	58	2.5	1.24	0.265
	25.0	259	31	254	18	0.0	-	-

* Corrected using Henderson and Tilton's (1955) modification of Abbot's formula.

[†] Probability that the control and treatment are not significantly different for corrected mortality greater than 0 (PROC FREQ, SAS Institute 1990)

by this time (Lyons 1994). The most likely explanation for the resistance of the eggs may be that the active ingredients in the formulations, azadirachtin and diflubenzuron, are both insect growth regulators and express their activity only against actively moulting stages of the insect (Retnakaran and Wright 1987; Schmutterer 1990). Conventional insecticides also had no effect on egg survival in similar bioassays (Lyons et al. 1993). We have been unable to find evidence that neem has any effect on insect eggs, except for egg hatchability of some homopteran species (Schmutterer 1995). However, ovicidal activity of diflubenzuron has been reported but is usually limited to mortality of fully formed larvae inside the egg (Retnakaran and Wright 1987).

At all application rates of Dimilin WP and Azatin EC tested in the laboratory in 1992, significant larval mortality was observed (Table III). For branches treated with Azatin EC, all doses greater than 15.0 g AI/ha resulted in 100% larval mortality. At doses greater than 5.0 g AI/ha only a few larvae survived. The lowest dose, 2.5 g AI/ha, of Azatin EC tested still provided greater than 50% mortality. Dimilin WP was also very active against larvae in 1992. The lowest dose tested, 3.125 g AI/ha, produced greater than 50% mortality. The decline in mortality at 25 g AI/ha may have been due to difficulties with spraying a wettable powder formulation at relatively high concentrations with the atomization system used in this study.

In bioassays conducted in 1994 (Table IV), all three products resulted in 77–94% mortality of larvae at 1.0 g AI/ha. The greatest mortality occurred on branches treated with Azatin EC. Neem EC and Dimilin WP produced significant and very similar mortality at dosages above 0.2 g AI/ha. Differences in mortality rates between treatment years, at comparable dosages, may have resulted from physiological differences in the experimental insects. Probit analysis yielded LC_{50} values (95% confidence intervals) of 0.37 g AI/ha (0.18–0.57) and 0.40 g AI/ha (0.32–0.48) for Neem EC and Dimilin WP, respectively. Slopes (SE) were 2.21 (0.17) and 1.99 (0.19). Dimilin WP and neem-based formulations are as or more toxic to pine false webworm larvae than conventional

TABLE II. Effects of neem and diflubenzuron formulations, applied to red pine branches in the laboratory six days after oviposition, on egg hatch of the pine false webworm in 1994.

		Number of eggs						
Product	Dosage	Control		Treatment		Corrected	χ^2	$P^†$
	(g AI/ha)	Alive	Dead	Alive	Dead	mortality*		
Azatin EC	1.0	254	34	255	22	0.0	-	-
Dimilin WP	0.008	150	23	170	13	0.0	-	-
	0.04	204	23	203	31	3.5	1.08	0.298
	0.2	242	40	271	27	0.0	-	-
	1.0	188	40	204	33	0.0	-	-
	5.0	84	20	80	19	0.0	-	-
Neem EC	0.008	156	13	170	20	3.1	0.86	0.354
	0.04	156	13	162	23	5.1	2.17	0.141
	0.2	194	30	218	18	0.0	-	-
	1.0	411	46	432	32	0.0	-	-
	5.0	159	26	155	23	0.0	-	-

* Corrected using Henderson and Tilton's (1955) modification of Abbot's formula.

[†] Probability that the control and treatment are not significantly different for corrected mortality greater than 0 (PROC FREQ, SAS Institute 1990)

TABLE III. Effects of neem and diflubenzuron formulations, applied to red pine branches in the laboratory six days after oviposition, on larvae of the pine false webworm in 1992.

		Number of larvae						
Product	Dosage	Control		Treatment		Corrected	χ^2	$P^†$
	(g AI/ha)	Alive	Dead	Alive	Dead	mortality*		
Azatin EC	2.5	38	4	14	35	68.4	35.39	<0.001
	5.0	246	38	5	280	97.9	415.56	<0.001
	10.0	217	83	3	281	98.5	315.67	<0.001
	15.0	212	39	0	236	100.0	349.57	<0.001
	20.0	50	3	0	41	100.0	78.89	<0.001
	25.0	213	60	0	289	100.0	363.10	<0.001
	50.0	212	23	0	232	100.0	383.30	<0.001
Dimilin WP	3.125	165	25	40	151	75.9	166.4	<0.001
	6.25	177	92	38	386	80.2	165.05	<0.001
	12.5	256	169	2	462	99.2	271.87	<0.001
	25.0	167	92	30	224	81.7	150.38	<0.001

* Corrected using Henderson and Tilton's (1955) modification of Abbot's formula.

[†] Probability that the control and treatment are not significantly different for corrected mortality greater than 0 (PROC FREQ, SAS Institute 1990)

TABLE IV. Effects of neem and diflubenzuron formulations, applied to red pine branches in the laboratory six days after oviposition, on larvae of the pine false webworm in 1994.

Product	Dosage (g AI/ha)	Number of larvae: Control Alive	Control Dead	Treatment Alive	Treatment Dead	Corrected mortality*	χ^2	$P^{\dagger}$
Azatin EC	1.0	210	45	12	243	94.3	312.72	<0.001
Dimilin WP	0.008	128	22	135	35	6.9	1.91	0.167
	0.04	170	34	169	34	0.1	0.00	0.982
	0.2	201	41	161	110	28.5	34.42	<0.001
	1.0	159	29	40	164	76.8	165.21	<0.001
	5.0	70	14	0	80	100.0	116.31	<0.001
Neem EC	0.008	126	30	142	28	0.0	-	-
	0.04	126	30	141	21	0.0	-	-
	0.2	157	37	129	89	26.9	22.88	<0.001
	1.0	336	75	62	370	82.4	383.91	<0.001
	5.0	130	29	1	154	99.2	212.40	<0.001

* Corrected using Henderson and Tilton's (1955) modification of Abbot's formula.

† Probability that the control and treatment are not significantly different for corrected mortality greater than 0 (PROC FREQ, SAS Institute 1990)

insecticides. Previous bioassays demonstrated that permethrin and carbaryl were the most active insecticides tested (Lyons et al. 1993). At 25 g AI/ha, the lowest dosage tested, these two insecticides resulted in 92 and 97% mortality, respectively. Dimilin WP and neem produced similar mortality at dosages of 5 g AI/ha. These laboratory bioassays also suggested that the two neem products possessed similar efficacy. These data and the declining availability of the Azatin EC formulation at this time shifted our emphasis to the Neem EC product in the 1994 and 1995 field trials.

Field Trials. The percentage egg hatch at the time of treatment in 1991, 1993, 1994 and 1995 was 53.3, 15.0, 20.8 and 47.4%, respectively. Thus, in all years, treatment was successfully timed to coincide with the period of egg hatch and the presence of newly emerged larvae.

Population reductions on upper branches were comparable to reductions on lower branches for most treatments (Table V) suggesting that spray deposits were evenly distributed on the vertical strata of the trees. Where significant differences occurred, the differences were small. Thus, mistblower applications are an effective method of applying control products to this size of plantation-grown trees. Larger trees receive smaller doses of the control products than do smaller trees at the fixed walking pace used in the current experiments. Heights of trees receiving control products in 1994 were similar, except for trees treated with Neem EC at 200 g AI/ha. The smaller size of these trees was inconsequential since maximum effects were observed at the lower dose of 50 g AI/ha. Control trees were significantly larger than treated trees in 1991 and 1994 but this should not have affected results (Table VI).

TABLE V. Mean (SE) population reduction of the pine false webworm on diflubenzuron- and neem-treated, and control red pine trees at Sprucedale, Ontario in 1991, 1993, 1994 and 1995.

				Percent population reduction (SE)		
Year	Treatment	Dosage (g AI/ha)	No. of trees	Upper branches	Lower branches	Both branches*
1991	control	-	40	40.6 (4.8)	55.9 (4.9)†	48.2 (3.5) b
	Dimilin WP	70.0	40	100.0 (0.0)	99.9 (0.1)	99.9 (0.1) a
1993	control	-	30	30.5 (5.1)	39.7 (5.9)	35.1 (3.9) c
	Dimilin WP	35.0	30	94.8 (3.3)	98.0 (1.0)	96.4 (1.7) a
	Azatin EC	50.0	30	62.4 (6.1)	85.0 (4.3)†	73.7 (4.0) b
1994	control	-	30	36.9 (6.5)	56.6 (6.3)†	46.8 (4.7) c
	Azatin EC	50.0	30	81.0 (4.9)	91.5 (4.0)	86.2 (3.2) b
	Azatin EC	200.0	30	99.0 (0.7)	100.0 (0.0)	99.5 (0.3) a
	Neem EC	50.0	30	89.7 (3.5)	96.9 (2.4)†	93.3 (2.1) ab
	Neem EC	200.0	30	98.5 (1.3)	96.5 (3.3)	97.5 (1.8) a
1995	control	-	30	66.1 (4.6)	65.3 (5.3)	65.7 (3.5) b
	Neem EC	50.0	30	69.0 (6.2)	87.8 (4.2)†	78.4 (3.9) a

[*] Means within a year and followed by the same letter, after arcsine square-root transformation of the data, are not significantly different [ANOVA and Tukey's studentized range test (PROC GLM, SAS Institute 1990)]

[†] Upper and lower branches significantly different (*t*-test; $P < 0.05$) (PROC TTEST, SAS Institute 1990)

In 1991, the effect of the Dimilin WP treatment at 70 g AI/ha on preventing tree damage and reducing populations of pine false webworm was dramatic. Population reductions on treated trees were almost 100% compared to a population reduction on control trees of only 48.2 % (Table V). Population reductions on the control trees, and perhaps on the treated trees, included loss from other mortality factors and completion of larval development. No defoliation was evident on any of the treated trees while adjacent upwind untreated trees sustained 76 and 40% defoliation of one-year-old and current-year foliage, respectively (Table VI). Trees in control rows suffered comparable damage to the upwind untreated trees. Pine false webworm feeds primarily on one-year-old and older foliage and only resorts to feeding on current-year foliage when one-year-old foliage has been mostly consumed on individual branch tips (Lyons 1995). In an ongoing outbreak such as the one in this plantation, there is seldom much foliage more than one-year-old and high larval densities often result in feeding on current-year foliage.

A lower application rate with Dimilin WP of 35 g AI/ha in 1993 still provided excellent control. This Dimilin WP treatment resulted in 96.4% population reduction compared to 35.1% on the control trees (Table V). The treated trees suffered only slight defoliation whereas adjacent untreated trees sustained an average of 93% defoliation of one-year-old needles (Table VI).

Treatment with Azatin EC at 50 g AI/ha in 1993 resulted in significant population reduction compared to the control (Table V) and corrected foliage protection levels of 37 and 72% to one-year-old and current-year's foliage (Table VI). In 1994, we compared the Azatin EC formulation

TABLE VI. Mean defoliation by the pine false webworm on diflubenzuron- and neem-treated, control and adjacent untreated red pine trees and corrected foliage protection of treated trees at Sprucedale, Ontario in 1991, 1993, 1994 and 1995.

Year	Treatment	Dosage (g AI/ha)	n	Mean (SE) tree height (m)	Foliage age	Mean (SE) defoliation (%)		*P*[*]	Corrected foliage protection (%)
						Treated row	Adjacent row		
1991	control	-	40	1.7 (0.05) a	1-year-old	69 (4.2)	63 (4.6)	0.273	-10
					current	30 (4.6)	22 (4.3)	0.253	-36
	Dimilin WP	70	40	1.4 (0.04) b	1-year-old	0 (0.0)	76 (4.7)	<0.001	100
					current	0 (0.0)	40 (5.5)	<0.001	100
1993	control	-	30	-[†]	1-year-old	67 (4.4)	60 (4.7)	0.144	-13
					current	20 (3.2)	15 (3.0)	0.089	-33
	Dimilin WP	35	30	-[†]	1-year-old	12 (1.0)	93 (2.0)	<0.001	87
					current	1 (0.6)	45 (3.0)	<0.001	97
	Azatin EC	50	30	-[†]	1-year-old	31 (2.8)	48 (4.4)	<0.001	37
					current	4 (0.9)	13 (2.1)	<0.001	72
1994	control	-	30	3.8 (0.08) a	1-year-old	67 (4.4)	60 (4.7)	0.144	-13
					current	20 (3.2)	15 (3.0)	0.089	-33
	Azatin EC	50	30	3.0 (0.09) b	1-year-old	26 (3.5)	77 (3.6)	<0.001	67
					current	5 (1.2)	19 (1.6)	<0.001	71
	Azatin EC	200	30	3.2 (0.12) b	1-year-old	11 (0.7)	80 (2.5)	<0.001	85
					current	2 (0.7)	26 (2.4)	<0.001	93
	Neem EC	50	30	3.1 (0.11) b	1-year-old	11 (1.1)	75 (5.0)	<0.001	85
					current	0 (0.3)	19 (2.4)	<0.001	98
	Neem EC	200	30	2.6 (0.10) c	1-year-old	10 (0.6)	88 (3.8)	<0.001	88
					current	1 (0.6)	43 (3.7)	<0.001	97
1995	control	-	30	2.5 (0.08) a	1-year-old	77 (3.4)	-[‡]	-	-
					current	26 (3.3)	-	-	-
	Neem EC	50	30	2.3 (0.14) a	1-year-old	9 (1.6)	53 (5.1)	<0.001	84
					current	0 (0.0)	5 (1.6)	<0.001	100

[*] Probability (*t*-test) that mean defoliation of treated and adjacent untreatd trees are not significantly different (PROC TTEST, SAS Institute 1990)

[†] Tree heights were not measured in 1993

[‡] Trees adjacent to control trees were not evaluated for defoliation in 1995

with the Neem EC formulation at 50 g AI/ha and at a higher dosage of 200 g AI/ha. Population reduction at the higher concentration of Azatin EC was almost 100% and was not significantly different from the population reduction achieved at 50 and 200 g AI/ha of Neem EC. The population reduction observed at 50 g AI/ha of Azatin EC was significantly lower than the other neem treatments, but still significantly better than the control (Table V). Mean defoliation values for all these treatments were significantly lower than for untreated upwind trees (Table VI). Corrected foliage protection of one-year-old foliage ranged from a low of 67% for Azatin EC at 50 g AI/ha to a high of 88% for Neem EC at 200 g AI/ha. For current foliage, corrected foliage protection ranged from 71% for Azatin EC at the lower dosage to 98% for Neem EC at 200 g AI/ha. In 1995, the Neem from 71% for Azatin EC at the lower dosage to 98% for Neem EC at 200 g AI/ha. In 1995, the Neem EC formulation again provided effective control at 50 g AI/ha. The protection of one-year-old and current-year foliage was 84 and 100% respectively.

Both Dimilin WP and the neem-based formulations, particularly Neem EC from PheroTech Inc., provided effective control of pine false webworm larvae at low dosages. These products performed as well as or better than permethrin and carbaryl in similar trials where concentrations of 35 and 125 g AI/ha resulted in one-year-old foliage protection levels of 42 and 40%, respectively (Lyons et al. 1993).

Dimilin WP proved to be exceptionally efficacious by ground application at peak egg hatch. This product has a significant residual life, persisting on foliage for several weeks (Sundaram 1991). This foliar persistence may explain its excellent activity under field conditions. The phenology of pine false webworm is protracted and susceptible stages may be present at different points in time (Lyons 1994). From a control point of view such long persistence is an asset but concerns have been expressed from an environmental perspective. Diflubenzuron-based insecticides have been implicated in the reduction of non-target aquatic insects (Griffiths et al. 1996; Hurd et al. 1996) and non-target lepidopterans (Sample et al. 1993). However, diflubenzuron may have a place in management of the pine false webworm in plantation-grown pines. In these habitats, non-target diversity is low and surface water is generally absent.

Insecticides formulated from neem seed extracts have a wide spectrum of activity to insects, but exhibit stage selectivity to immature, non-target insects (Schmutterer 1997). Consequently, these products produce negligible or only slight side effects on beneficial insects under field conditions. Neem-based insecticides have been tested against a variety of aquatic macroinvertebrates and exhibit little risk of direct adverse effects (Kreutzweiser 1997). They also possess short persistence in the environment (Sundaram et al. 1997). Thus, neem-based insecticides are a low risk environmentally, are efficacious against pine false webworm and offer a viable alternative to conventional insecticides for its control in immature red pine plantations.

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COMPARISON OF WHITE AND YELLOW TINTS ON COLOURED STICKY TRAPS FOR MONITORING *DELIA* SPP. (DIPTERA: ANTHOMYIIDAE) IN ONION AND CABBAGE FIELDS IN ONTARIO

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Abstract

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Trap captures of adults of *Delia antiqua* (Meigen), *D. radicum* (L.) and *D. platura* (Meigen) on sticky traps were compared among traps painted bright yellow, non-UV-reflecting white and three tints of yellow in an onion field and a cabbage field in Ontario. The yellow tints had increasing amounts of white added ranging from the yellowest tint (YT1) to the whitest tint (YT3). Trap captures of *D. antiqua* were highest for white traps and YT3 traps, intermediate for YT2 traps and lowest for yellow and YT1 traps in both onion and cabbage fields. Similar results were obtained for *D. platura* where higher captures were recorded for white traps or traps with more white present in both onion and cabbage fields. Trap colour did not significantly influence trap captures of *D. radicum* on sticky traps in either the onion or the cabbage field. The proportion of *D. antiqua* captured relative to the other two *Delia* species was not influenced by trap colour in the onion field. In the cabbage field, the proportion of *D. antiqua* captured was significantly higher for YT2, YT3 and white traps than for yellow or YT1 traps. The proportion of *D. radicum* captured relative to the other two *Delia* species was significantly higher for yellow and YT1 traps than for YT2, YT3 or white traps. Trap capture data and data for the proportion of particular species captured is discussed as it relates to the use of coloured sticky traps for monitoring populations of *D. antiqua* and *D. radicum* for pest management purposes in Ontario.

KEYWORDS *Delia antiqua*, *Delia radicum*, *Delia platura*, colour response, sticky traps, pest-management monitoring

Coloured sticky traps are used to monitor populations of the onion maggot, *Delia antiqua* (Meigen) (Diptera: Anthomyiidae), for pest management purposes in several areas of North America (Eckenrode et al. 1975; Liu et al. 1982; Whitfield et al. 1985; Vernon et al. 1989; Chaput 1996). A number of aspects of trap colour have been shown to influence the level of attraction of *Delia* spp. to sticky traps (Vernon and Bartel 1985; Judd 1986; Vernon 1986; Judd et al. 1988; Kostal and Finch 1996; Vernon and Broatch 1996). When choosing a trap colour for a monitoring program, it is desirable to maximize visual attraction of the target species, and minimize concurrent attraction of other *Delia* spp. that may be misidentified on traps. Misidentification of *Delia* spp. on sticky traps by pest management personnel may lead to incorrect pest management recommendations that result in unnecessary pesticide applications. This paper reports on captures of *D. antiqua* and two other *Delia* spp. on yellow and white sticky traps placed in commercial onion and cabbage fields in Ontario.

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Yellow sticky traps are currently used in Ontario and Michigan for monitoring populations of adult *D. antiqua* (Liu et al. 1982; Whitfield et al. 1985; Chaput 1996). In Ontario, the traps consist of yellow-tinted milk cartons coated with an adhesive, inverted over wooden stakes, and placed in groups of three in and around onion fields. Yellow, however, is not the most attractive colour for British Columbia (BC) populations of this insect. White was found to be about four times more attractive than bright yellow to *D. antiqua* (Vernon and Bartel 1985; Judd 1986), and white sticky traps are used in commercial monitoring programs in BC (Vernon et al. 1989). No information is currently available on the relative attraction of Ontario populations of *D. antiqua* to white and yellow traps.

If Ontario populations of *D. antiqua* respond to white sticky traps in a manner similar to BC populations, it may be advisable to use white sticky traps for monitoring in Ontario in order to maximize trap catch. However, because Ontario populations have been historically high, white traps may saturate with flies more quickly than in BC and make it impossible to detect changes in population level over time. In addition, all field data and action thresholds for spray recommendations in Ontario have been based on the use of yellow traps since 1981. If white traps were used in Ontario, further research would be required to develop methods for converting and interpreting data between traps of different colours.

One disadvantage of using either white or yellow sticky traps for monitoring *D. antiqua* is that these traps also capture other *Delia* species like the cabbage maggot, *D. radicum* L., or the seed-corn maggot, *D. platura* (Meigen). In BC, white sticky traps used in onions may become saturated with one, or both, of these contaminant species, which can considerably reduce the effectiveness of sticky traps for monitoring *D. antiqua* populations. Misidentification of *Delia* species does not usually occur in BC because traps are returned to the laboratory where flies are identified using dissecting microscopes. In Ontario, however, counts are made directly on yellow traps in the field by pest management scouts, which increases the potential for misidentification. Therefore, selection of a trap colour that is more specific to *D. antiqua* than other coincident *Delia* species would reduce saturation problems and improve the speed and accuracy of fly identifications in the field.

When white was added to bright yellow to produce a series of yellow-tinted traps, the attraction of *D. antiqua* in BC onion fields increased linearly as the amount of white in the traps increased (Vernon and Bartel 1985; Judd 1986). In contrast, the addition of white to yellow caused an initial decrease in attraction of *D. radicum* to traps of intermediate yellow tints, and a subsequent increase in attraction as the amount of white in the traps was further increased (R.S. Vernon, unpublished data). Intermediate tints of yellow may thus minimize attraction of *D. radicum* to traps, while still increasing *D. antiqua* attraction compared to the bright yellow traps currently used in Ontario.

In the present study, trap captures of *D. antiqua*, *D. radicum*, and *D. platura* on white traps and yellow traps tinted with increasing amounts of white were compared in an onion field and a cabbage field in Ontario. Our primary objective was to determine the trap colour that maximized captures of *D. antiqua* and simultaneously minimized captures of the contaminating species (*D. radicum* and *D. platura*). A secondary objective was to determine the trap colour that maximized captures of *D. radicum* and minimized captures of *D. antiqua* and *D. platura* in order to make a recommendation for the optimal trap colour for monitoring *D. radicum* in cabbage plantings.

Materials and Methods

Trap preparation. Paints were applied in two coats to one side of sheets of white cardboard (56 by 72 cm, 4-ply Railroad Board, Domtar Fine Papers, Toronto ON Canada). All paints used were obtained from Cloverdale Paint and Chemicals (CP) (Surrey BC Canada). Paints used were: non-UV-reflective white (alkyd semigloss enamel), three yellow tints (YT1, YT2 and YT3), and yellow (CP 776). The yellow tints from YT1 to YT3 had increasing amounts of the non-UV-reflective white paint added to the yellow 776 paint. Visible reflectance spectra of newly-made traps of the above five colours (and the yellow colour currently used for *D. antiqua* traps in Ontario) were obtained using a Hunterlab Model D-53 Spectra Sensor with a barium sulfate standard (Fig. 1).

The painted sheets were cut into 11 × 14 cm rectangles and coated with Stikem Special (Seabright Enterprises, Emeryville, California).

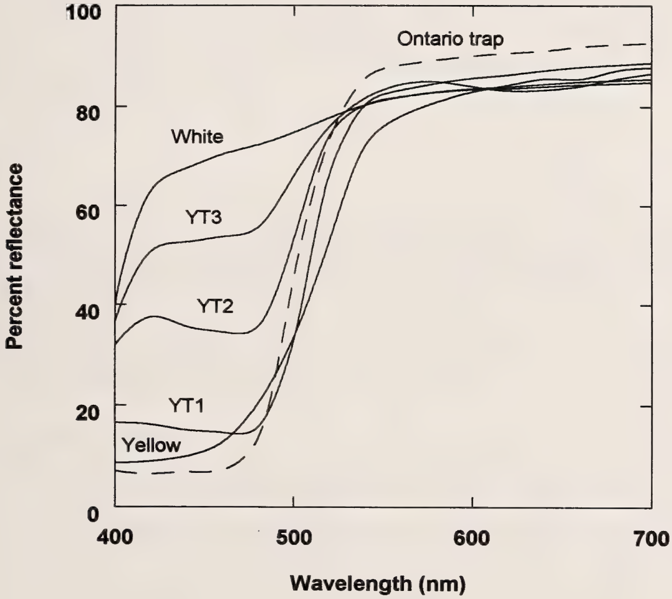

FIGURE 1. Spectral reflectance curves for cardboard traps used for trapping of *Delia* species in Ontario. Traps were painted with bright yellow, three yellow tints (YT1, YT2 and YT3) and white. Spectral reflectance for the yellow trap currently used in Ontario is shown as a dashed line.

Field plots and experimental design. A four-hectare commercial field of cooking onions planted with a mixture of late-storage varieties was chosen for the onion trap trial. A two-hectare commercial field of cabbage (varieties Saratoga and Amtrak) was chosen for the cabbage trap trial. Sticky traps were clipped at the 11 cm edge to 1 × 3 cm wooden stakes with the trap tops 30 cm above the ground. Traps of each of the five colours were placed in five replicate plots arranged 1.5 m inside the west edge of the onion field and 1.5 m inside the east edge of the cabbage field. The traps were placed 5 m apart with 10 m between replicate plots in a linear randomized complete block design. The coloured sides were oriented to face east and west. Traps were first placed in the field on 17

July 1995 (trapping session 1), and traps were replaced seven times over the course of the season on 20, 24, and 28 July, and 2, 8, 14, and 22 August (trapping sessions 2 through 8). The final set of traps was removed from the field on 29 August. *Delia* species were identified on the sticky traps with a dissecting microscope using the diagnostic key of Brooks (1951). The numbers of male and female *D. antiqua*, *D. radicum*, and *D. platura* captured on each trap were recorded.

Statistical analysis. All trap capture data were square-root transformed (i.e. sqrt (X + 0.5)) before analysis of variance (ANOVA). The proportions of particular *Delia* species captured on the traps relative to all adult *Delia* captured were calculated to evaluate the level of attraction of "target species" for trapping programs relative to non-target contaminants. We calculated the proportion of: (1) *D. antiqua* captured per trap in the onion field, (2) *D. antiqua* captured per trap in the cabbage field, and (3) *D. radicum* captured per trap in the cabbage field. Proportional data were arcsine transformed before analysis (i.e. arcsin(sqrt (X)). Single factor ANOVA by trap colour was conducted for captures of males and females of the three *Delia* species, and for the proportions of target species captured. Means were distinguished among treatments using Tukey tests. All statistical analyses were conducted using Systat for Windows, Version 5.0 (Wilkinson et al. 1992).

Results

Trap captures in the onion field. Total captures of *D. antiqua* on sticky traps in the onion field were highest on the white traps and YT3 traps, intermediate on YT2 traps, and lowest on yellow traps and YT1 traps (Fig. 2D, Table I). Total captures of *D. radicum* on traps in the onion field were not significantly different among trap colours, and were extremely low compared to captures of *D. antiqua* (Fig. 2E, Table I). Trap captures of *D. platura* showed a pattern similar to that observed for *D. antiqua*. Total captures of *D. platura* were highest for white traps and YT3 traps, intermediate for YT2 traps, and lowest for yellow traps and YT1 traps (Fig. 2F, Table I). The pattern of captures on traps of different colours was similar for males and females of all three species (Table I).

The pattern of captures of both *D. antiqua* and *D. platura* on traps of different colours was similar in individual trapping sessions across the season (Fig. 2A and 2C) to the pattern observed in the pooled data for the entire season (Fig. 2D and 2F). White and YT3 traps always caught the highest number of flies for both *D. antiqua* and *D. platura* (Fig. 2A and 2C). No qualitative variation in the ranking of trap colours across the season was observed for these two species. Captures of *D. radicum* in the onion field mainly occurred during the fifth trapping session (2–8 August) (Fig. 2B). When data was analysed individually for the fifth trapping session, no effect of trap colour on captures of *D. radicum* could be detected for pooled male plus female data, or that for males or females alone (ANOVA by trap colour: pooled data: F = 0.68, df = 4, p = 0.61, males: F = 0.61, df = 4, p = 0.66, females: F = 0.28, df = 4, p = 0.89).

No differences among trap colours were detected in the proportion of *D. antiqua* captured in the onion field (relative to *D. radicum* and *D. platura*) when data was analysed for male flies, or for total captures of male and female flies (Table II). The proportion of female *D. antiqua* captured (relative to *D. radicum* and *D. platura*) was significantly higher for YT2, YT3 and white traps than for YT1 traps, and significantly higher for YT2 traps than for yellow traps (Table II).

Trap captures in the cabbage field. Similar to what was observed in the onion field, total captures of *D. antiqua* on sticky traps in the cabbage field were highest on white and YT3 traps, intermediate on YT2 traps and lowest on yellow and YT1 traps (Fig. 3D, Table III). Four levels of total captures of *D. platura* on traps of different colours were detected in the cabbage field. White

TABLE I. Mean captures (± SE) of three *Delia* species on coloured sticky traps placed in a commercial onion field. F-statistics and significance levels are given for Analyses of Variance (ANOVA) of trap captures by trap colour for particular species or combinations of species and sex. Degrees of freedom are equal to 4 for all ANOVA. Means in rows followed by the same letter are not significantly different at p = 0.05 by Tukey tests.

Species	Sex	Trap colour					Analysis of variance	
		Yellow	YT1	YT2	YT3	White	F	p
Delia antiqua	Male	4.3±0.6 d	3.4±0.5 d	13.5±1.6 c	23.2±2.1 b	30.8±2.4 a	76.8	<0.001
	Female	1.1±0.2 c	0.9±0.2 c	4.6±0.5 b	11.4±1.0 a	12.5±1.1 a	94.3	<0.001
	Total	5.4±0.8 c	4.3±0.6 c	18.1±2.0 b	34.7±2.7 a	43.3±3.1 a	98.7	<0.001
Delia radicum	Male	0.1±0.0 a	0.2±0.1 a	0.2±0.1 a	0.3±0.2 a	0.1±0.1 a	0.4	0.82
	Female	0.1±0.1 a	0.1±0.1 a	0.1±0.0 a	0.1±0.0 a	0.1±0.1 a	0.1	0.98
	Total	0.2±0.1 a	0.3±0.2 a	0.2±0.2 a	0.4±0.2 a	0.2±0.1 a	0.2	0.93
Delia platura	Male	0.1±0.1 b	0.1±0.1 b	0.7±0.1 b	2.0±0.4 a	2.9±0.5 a	24.1	<0.001
	Female	0.1±0.0 c	0.1±0.1 c	1.6±0.5 b	3.6±0.6 a	4.6±0.8 a	23.6	<0.001
	Total	0.1±0.1 c	0.2±0.1 c	2.3±0.6 b	5.6±0.9 a	7.4±1.2 a	29.5	<0.001

traps captured higher numbers of *D. platura* than YT3 traps, which in turn captured more than YT2 traps, and which in turn captured more than either YT1 or yellow traps (Fig. 3F, Table III). Slight differences in the number of levels detected (by Tukey tests) in mean trap captures occurred when data for *D. antiqua* or *D. platura* were analysed for only male or female flies (Table III). However, the pattern of increasing attraction to traps with more white present was consistent for both sexes of *D. antiqua* and *D. platura*.

Analysis of variance in trap captures for *D. radicum* in the cabbage field showed significant variation among trap colours for female flies, and marginally significant variation among trap colours for males and for data pooled for both sexes (Fig. 3E, Table III). However, Tukey tests failed to show significant differences among mean trap captures for different trap colours for males, females or total *D. antiqua* (Table III). A marginally significant difference was detected for female *D. radicum* where captures were higher on YT3 traps than on yellow traps. Similarly, a marginally significant difference was detected for male *D. radicum* where captures were higher on YT3 traps than on YT2 traps.

Similar to what was observed in the onion field, the rankings of attractiveness of trap colours for *D. antiqua* and *D. platura* in the cabbage field were similar in individual trapping sessions to what was observed in data pooled over the entire season (Fig. 3A and 3C). Because changes in the rankings of attractiveness of trap colours occurred across individual trapping sessions for *D. radicum* (Fig. 3B), separate ANOVA by trap colour were conducted for male, female and pooled trap captures for the eight trapping sessions. Although none of these ANOVA were significant, three analyses showed marginally significant trends. Marginally significant variation in female trap capture was detected in both trapping sessions 2 (F = 2.6, df = 4, p = 0.08) and 3 (F = 2.5, df = 4, p = 0.08). *Post hoc* linear contrasts on these data showed a significant increase in female trap capture with increasing amounts of white in traps (linear contrast by trap colour: trapping session 2: F = 9.7, df = 1, p = 0.006; trapping session 3: F = 9.5, df = 1, p = 0.007). Marginally significant variation in male trap capture was detected in trapping session 8 (F = 2.2, df = 4, p = 0.10). A *post hoc* quadratic contrast on these data was significant (quadratic contrast by trap colour: F = 6.0, df = 1,

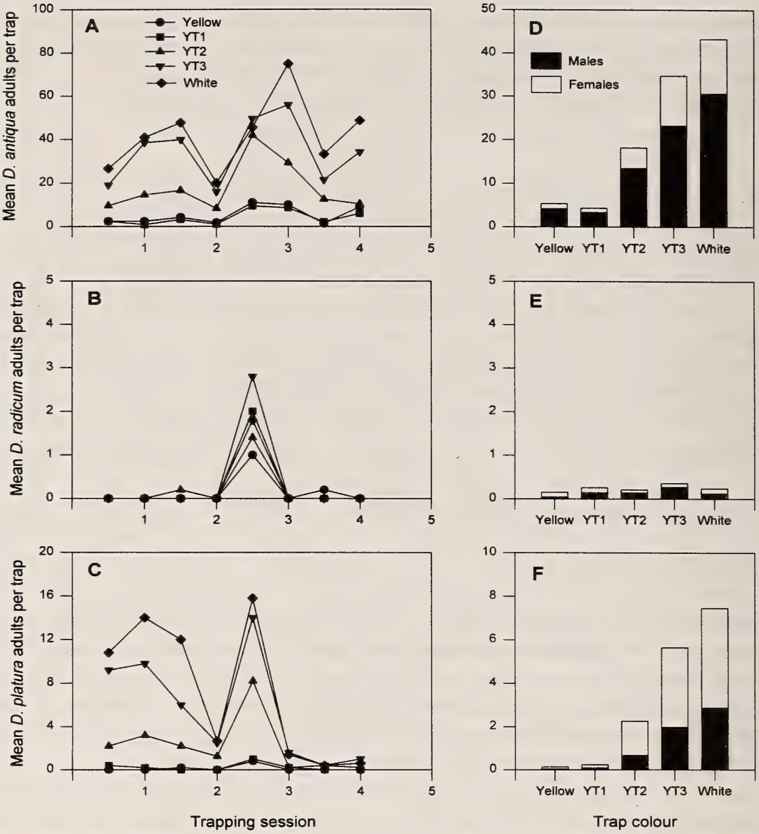

FIGURE 2. Trap captures of three *Delia* species on coloured sticky traps in an onion field. Mean captures for individual trapping sessions during the season are shown for yellow, YT1, YT2, YT3 and white traps for (A) *D. antiqua*, (B) *D. radicum* and (C) *D. platura*. Mean captures of males (black bars) and females (white bars) pooled over the season are shown for the five colours for (D) *D. antiqua*, (E) *D. radicum* and (F) *D. platura*.

$p = 0.023$) indicating a trend to lower trap capture at intermediate (i.e. YT2) yellow tints during trapping session 8.

The proportion of *D. antiqua* captured on traps (relative to *D. radicum* and *D. platura*) in the cabbage field was significantly higher for white, YT3 and YT2 traps than for YT1 or yellow traps when data was analysed for females or for data pooled for both sexes (Table II). For male flies, a similar pattern of variation was observed where the proportion of *D. antiqua* captured was higher in traps with more white present than in yellow traps. However, significant differences were only detected between white and YT3 traps vs. yellow traps (Table II). The proportion of *D. radicum* captured on traps (relative to *D. antiqua* and *D. platura*) was significantly higher for yellow and YT1 traps than for YT2, YT3 or white traps when data was analysed for males or for data pooled for both sexes (Table II). A similar pattern was observed for female flies where the proportion of *D. radicum* captured was highest for yellow and YT1 traps (Table II).

TABLE II. Proportion of target species (± SE) among captures of three *Delia* species on coloured sticky traps. F-statistics and significance levels are given for Analyses of Variance (ANOVA) of trap captures by trap colour for particular species or combinations of species and sex. Degrees of freedom are equal to 4 for all ANOVA. Means in rows followed by the same letter are not significantly different at p = 0.05 by Tukey tests.

Species	Sex	Trap colour					Analysis of variance	
		Yellow	YT1	YT2	YT3	White	F	p
Delia antiqua in onions	Male	0.89±0.05 a	0.76±0.07 a	0.94±0.01 a	0.90±0.02 a	0.90±0.02 a	1.9	0.11
	Female	0.52±0.08 b	0.38±0.08 c	0.77±0.04 a	0.77±0.03 ab	0.77±0.03 ab	8.6	<0.001
	Total	0.90±0.04 a	0.79±0.06 a	0.90±0.02 a	0.86±0.02 a	0.85±0.02 a	1.8	0.14
Delia antiqua in cabbage	Male	0.12±0.04 b	0.23±0.06 ab	0.24±0.05 ab	0.34±0.04 a	0.34±0.04 a	4.8	0.001
	Female	0.05±0.03 b	0.02±0.01 b	0.20±0.05 a	0.15±0.03 a	0.13±0.03 a	8.6	<0.001
	Total	0.10±0.03 b	0.11±0.03 b	0.23±0.04 a	0.26±0.03 a	0.23±0.03 a	8.0	<0.001
Delia radicum in cabbage	Male	0.56±0.07 a	0.46±0.07 a	0.22±0.04 b	0.27±0.04 b	0.20±0.04 b	6.6	<0.001
	Female	0.54±0.07 ab	0.66±0.06 a	0.35±0.05 bc	0.32±0.03 bc	0.21±0.03 c	9.8	<0.001
	Total	0.59±0.06 a	0.67±0.05 a	0.31±0.04 b	0.30±0.03 b	0.20±0.02 b	16.5	<0.001

TABLE III. Mean captures (± SE) of three *Delia* species on coloured sticky traps placed in a commercial cabbage field. F-statistics and significance levels are given for Analyses of Variance (ANOVA) of trap captures by trap colour for particular species or combinations of species and sex. Degrees of freedom are equal to 4 for all ANOVA. Means in rows followed by the same letter are not significantly different at p = 0.05 by Tukey tests.

Species	Sex	Trap colour					Analysis of variance	
		Yellow	YT1	YT2	YT3	White	F	p
Delia antiqua	Male	0.4±0.1 b	0.6±0.2 b	1.7±0.3 b	4.0±0.6 a	4.8±0.8 a	22.6	<0.001
	Female	0.1±0.1 c	0.1±0.2 c	1.0±0.2 b	1.5±0.2 a	1.9±0.3 a	17.1	<0.001
	Total	0.6±0.1 c	0.7±0.2 c	2.8±0.5 b	5.5±0.7 a	6.7±1.0 a	28.6	<0.001
Delia radicum	Male	1.8±0.3 a	1.7±0.3 a	1.3±0.3 a	2.4±0.3 a	2.3±0.4 a	2.1	0.08
	Female	1.9±0.3 a	2.1±0.3 a	2.6±0.5 a	3.5±0.5 a	3.5±0.6 a	2.7	0.03
	Total	3.8±0.5 a	3.8±0.5 a	3.9±0.7 a	6.0±0.7 a	5.8±0.9 a	2.4	0.05
Delia platura	Male	0.6±0.2 c	0.5±0.1 c	2.4±0.4 b	4.2±0.6 a	5.3±0.7 a	30.1	<0.001
	Female	0.7±0.2 d	0.6±0.1 d	2.9±0.5 c	6.1±1.0 b	9.7±1.5 a	40.5	<0.001
	Total	1.4±0.3 d	1.1±0.2 d	5.3±0.8 c	10.3±1.6 b	15.0±2.1 a	45.4	<0.001

Discussion

Trap captures of *D. antiqua* were highest on white traps and traps tinted with increasing amounts of white than on yellow traps in both the onion and cabbage fields. This pattern of increasingly higher capture on yellow traps tinted with greater amounts of white is identical to that observed for BC populations of *D. antiqua*, and is caused by increased spectral reflectance at wavelengths between 400 and 500 nm (Vernon and Bartel 1985; Judd 1986). Although captures of

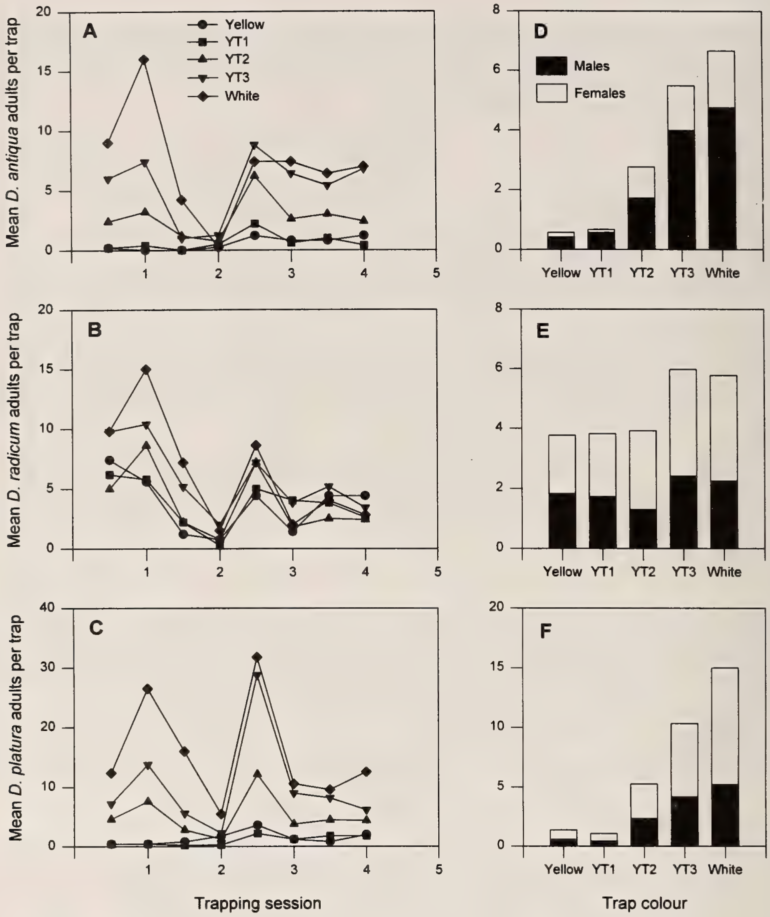

FIGURE 3. Trap captures of three *Delia* species on coloured sticky traps in a cabbage field in Ontario. Mean captures for individual trapping sessions during the season are shown for yellow, YT1, YT2, YT3 and white traps for (A) *D. antiqua*, (B) *D. radicum* and (C) *D. platura*. Mean captures of males (black bars) and females (white bars) pooled over the season are shown for the five colours for (D) *D. antiqua*, (E) *D. radicum* and (F) *D. platura*.

flies on white or YT3 traps were highest in both onion and cabbage plantings, trap saturation was not a problem in this study (only one trap in the onion field had 100 *D. antiqua* present which is a trap catch bordering on saturation). Based on the data from this study, we cannot recommend against the use of white traps for monitoring *D. antiqua* in Ontario based on the risk of trap saturation. The population level of *D. antiqua* in the field used for this study was similar to other onion fields in the Holland Marsh area in 1995, and populations of *D. antiqua* are often lower in other onion-growing areas in Southwestern Ontario. However, trap saturation could still be a problem during years when *D. antiqua* populations were high.

The lowest captures of BC populations of *D. radicum* on yellow-coloured traps occur at intermediate yellow tints (R.S. Vernon, unpublished data). Captures are higher on both white and yellow traps (and for tints closer to white and yellow) than captures on traps of intermediate tints of yellow. A similar pattern of response to yellow-tinted traps has also been recorded for BC populations of western flower thrips, *Frankliniella occidentalis* (Pergande) (Vernon and Gillespie 1990). This type of response was recorded in this study only as a marginally significant trend for male *D. radicum* in the cabbage field during one particular trapping session (trapping session 8). Marginally significant trends for increasing captures on traps with more white present were recorded for female *D. radicum* in two trapping sessions in the cabbage field (trapping sessions 2 and 3). In general, however, data from this study indicate that captures of *D. radicum* on sticky traps do not vary among the trap colours that were tested. There is virtually no evidence, from this one-year study, that the type of response observed in BC for *D. radicum* occurs in Ontario populations of this insect. Thus, data from this study provide no basis for recommending a trap with an intermediate yellow tint for use in Ontario to increase *D. antiqua* captures and concurrently minimize captures of *D. radicum.*

The pattern of captures of *D. platura* on coloured sticky traps was very similar to that observed for *D. antiqua*. In both onion and cabbage fields, trap captures of *D. platura* increased with increasing amounts of white in traps. Because the patterns of attraction of *D. platura* and *D. antiqua* are virtually identical, no trap colour can be selected that will simultaneously maximize *D. antiqua* captures and minimize those of *D. platura*. In BC, *D. platura* populations can occasionally reach levels that cause saturation of traps used to monitor *D. antiqua*. In light of the responses recorded in this study, it is likely that *D. platura* would also cause trap contamination problems in Ontario when population levels are high.

In the present study, trap contamination was not a problem in the onion field. Captures of *D. radicum* and *D. platura* were low compared to *D. antiqua*, and trap colour did not influence the proportion of *D. antiqua* captured on traps in the onion field. The experiment in the cabbage field might simulate a situation where *D. antiqua* was being monitored in a location adjacent to plantings of cabbage, or where *D. radicum* or *D. platura* populations were high. Data from the cabbage field indicate that YT2, YT3 and white are the trap colours that maximize the proportion of *D. antiqua* captured relative to contaminants. Because YT3 and white are also the most attractive colours for capture of *D. antiqua*, the use of these colours can be recommended as more effective for trapping *D. antiqua* in Ontario than the currently-used yellow traps (the Ontario yellow traps are assumed to have similar attractive properties for *Delia* spp. to the yellow traps tested in this study because their spectral reflectance properties at wavelengths between 400 and 500 nm are similar). However, methodology for converting trap capture data between the currently-used yellow traps and white traps is required before a change to white traps would be practical.

No sticky-trap monitoring program currently exists for management of *D. radicum* in cabbage fields in Ontario. Because of the higher captures of both *D. antiqua* and *D. platura* on traps with more white present, the proportion of *D. radicum* captured in the cabbage field in this study was higher on yellow and YT1 traps than on YT2, YT3 or white traps. If a sticky-trap monitoring program for *D. radicum* was to be established in Ontario, yellow or YT1 traps would be the optimal trap colours to maximize *D. radicum* captures and minimize trap contaminants.

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INSECTICIDE ENCAPSULATION TO MAINTAIN PREDATORY MITE POPULATIONS, REDUCE EUROPEAN RED MITE OUTBREAKS, AND CONTROL OF THE ORIENTAL FRUIT MOTH *GRAPHOLITHA MOLESTA* (BUSCK)

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Abstract

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The Oriental fruit moth, *Grapholitha molesta* (Busck), is the most economically significant insect pest in Ontario peach orchards. The currently recommended spray program to control *G. molesta* includes chlorpyrifos and cypermethrin. These insecticides are highly toxic to predatory phytoseiid mites, and outbreaks of phytophagous spider mites, including the European red mite, *Panonychus ulmi* (Koch), often occur after their use. We examined the effects of micro-encapsulation of chlorpyrifos and cypermethrin on the control of *G. molesta*, and on the conservation of predatory mites such as *Amblyseius fallacis* (Garman), in a peach orchard. Predatory mites were significantly more abundant in treatments with micro-encapsulated cypermethrin than in treatments with emulsifiable concentrations (EC) of cypermethrin. No difference in toxicity to phytoseiid predators was observed between micro-encapsulated chlorpyrifos and chlorpyrifos EC formulations. However, although some treatments had few phytoseiid predators, no differences were observed in *P. ulmi* populations between treatments. For *G. molesta* in the fruit sample, significantly higher populations (3.75% of fruit damaged) were observed in the all-micro-encapsulated treatments relative to the treatments with EC formulations (0.75% fruit damaged). However, damage in neither treatment was significantly different from the *G. molesta* damage observed in control treatments (1.00%). These results confirm that micro-encapsulated cypermethrin is more selective in an orchard integrated pest management program, but may be less toxic to *G. molesta* than EC formulations.

Introduction

The Oriental fruit moth, *Grapholitha molesta* (Busck), is the most important insect pest in Ontario peach orchards (Pree et al. 1998; Walker et al. in press). Insecticides are applied to control *G. molesta* in each of its three to four annual generations. Historically, the control program has used pheromone trap catch data to time applications of azinphosmethyl or phosmet to control *G. molesta* neonate larvae (Phillips 1973), which is the life-stage most sensitive to these chemicals (Pree 1979). In terms of an integrated pest management program, these chemical treatments were useful because mite predators of the family Phytoseiidae had evolved resistance to azinphosmethyl and phosmet (Croft and Nelson 1972; Watve and Lienk 1976). In this spray program, phytoseiid predators such as *Amblyseius fallacis* (Garman) persisted and were associated with the biological control of the European red mite, *Panonychus ulmi* (Koch) (D.J. Pree, unpublished data). In 1989, however, large increases in *G. molesta* trap catches and significant crop damage were observed. Damage rates subsequently increased to 20–30% of the peach crop in 1993 (G.M. Walker, OMAFRA, Vineland Station, Ontario, unpublished data). Laboratory tests indicated increased *G. molesta* resistance to phosmet and azinphosmethyl, but no resistance to either chlorpyrifos or pyrethroids (Pree et al. 1998). Subsequently, a spray program of one application of chlorpyrifos followed by three sprays of cypermethrin has been developed and recommended for commercial use (Walker et al. in press).

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A significant problem with pyrethroids is their toxicity to a broad range of arthropods including natural enemies of pests inhabiting orchards (Croft 1990). The toxicity of pyrethroids to phytoseiids such as *A. fallacis* has resulted in a worldwide decreased abundance of these predators and consequent outbreaks of *P. ulmi* to economically damaging densities (e.g. Penman and Chapman 1988; Gerson and Cohen 1989; Croft 1990). Pree et al. (1998) recognized this problem, and recommended the development and use of products to control *G. molesta* that were more compatible with an integrated pest management program, and especially a program that is more compatible with predatory mites.

One method to increase the selectivity of pesticides to phytophagous pests and reduce toxicity to natural enemies is micro-encapsulation. For example, Lester et al. (1999) found that micro-encapsulated cypermethrin was 12.4 times less toxic to pyrethroid susceptible populations of *A. fallacis* than was cypermethrin EC. Further, a pyrethroid-resistant strain of *A. fallacis* was significantly less susceptible to micro-encapsulated cypermethrin than to cypermethrin EC. A spray trial in an apple orchard showed micro-encapsulated cypermethrin conserved significantly higher numbers of *A. fallacis* than did cypermethrin EC, an effect which was correlated with a significantly lower population of *P. ulmi* than on cypermethrin EC sprayed trees (Lester et al. 1999). However, the question remains as to the effectiveness of micro-encapsulated pyrethroids against target pests such as *G. molesta*. In other studies, micro-encapsulated pesticides have been found to be useful. Chamberlain and Symes (1993) found that micro-encapsulated cypermethrin was as effective as cypermethrin EC in controlling a mixed species aphid population on barley and also that active residues persisted longer. Asquith et al. (1976) and Hull (1979) showed that encapsulated parathion controlled lepidopteran pests, and showed a reduced toxicity to *A. fallacis* and *Stethorus* spp.

Our aim in this study was to compare the toxicity of micro-encapsulated and EC formulations of chlorpyriphos and cypermethrin to predatory mites in a peach orchard, and examine the effects of these treatments on *P. ulmi* populations. We also wanted to assess the efficacy of micro-encapsulated and regular pesticide sprays on the control of *G. molesta*.

Methods

The study was conducted in a two-year-old peach orchard cv. Harrow Beauty at the Agriculture and Agri-Food experimental farm near Jordan Station, Ontario in 1998. Trees were spaced 4.5 × 5.5 m apart. The spray treatments examined chlorpyrifos (LORSBAN™ 50 WP, Dow-Agro Sciences, Newmarket, Ontario), a micro-encapsulated preparation of chlorpyrifos (DURSBAN™ 200 EC, 3M Canada Ltd., London, Ontario), cypermethrin (CYMBUSH™ 250 EC, 25 g a.i. litre^{-1}, Zeneca Agro, Stoney Creek, Ontario) and a micro-encapsulated formulation of cypermethrin (250 g a.i. litre^{-1}, 3M Canada Ltd., London, Ontario). There were 9 spray treatments examined: (1) control (no insecticides); (2) four applications of chlorpyrifos; (3) four applications of micro-encapsulated chlorpyrifos; (4) four applications of cypermethrin; (5) four applications of micro-encapsulated cypermethrin; (6) the recommended spray program of one application of chlorpyrifos and three applications of cypermethrin; (7) one application of chlorpyrifos and three of micro-encapsulated cypermethrin; (8) one application of micro-encapsulated chlorpyrifos and three of cypermethrin; and (9) one application of micro-encapsulated chlorpyrifos and three of micro-encapsulated cypermethrin.

The timing of the pesticide applications was determined from pheromone trap catches of *G. molesta*. Treatments were applied at estimated egg hatch (Pree et al. 1983). The first spray was applied on 13 May for the first *G. molesta* generation, the second spray on 26 June for the second generation, and the last two sprays for the third generation on 29 July and 11 August. Individual replicates of each treatment consisted of three tree plots. Treatments were replicated four times and arranged according to a randomized block design. All insecticides were diluted in water, and sprayed at a rate of 3000 L spray mixture ha^{-1}, to runoff, with a Rittenhouse (Rittenhouse Sprayers Ltd., St. Catharines, Ontario) truck-mounted sprayer, equipped with a handgun (Spraying Systems Co., Wheaton, Illinois) with a D-6 orifice plate, with the pressure set at 2000 kPa. Approximately 15–16 L of spray mix was used per plot.

Only two other pesticides were applied to this orchard. Dormant oil was applied on 6 April, at 40 L ha^{-1} in a water rate of 850 L ha^{-1}. The fungicide iprodione was applied on 14 August, at 1.0 kg AI ha^{-1} in a water rate of 500 L water ha^{-1}.

Predatory and phytophagous spider mites densities were estimated with 30 leaf samples, which comprised of 10 leaves from each tree in the three tree plots which were combined to make one sample. Leaves were collected in a random fashion from the entire tree. Six samples were collected during the season, on 5 May, 23 June, 14 July, 3 August, 19 August and 8 September. These dates correspond to Julian days 148, 174, 195, 215, 231 and 251. In the laboratory, mites were brushed from the leaves onto a glass plate using a Henderson-McBurnie mite brushing machine (Henderson and McBurnie 1943), and examined using a binocular microscope. Eggs and motile stages were counted separately. All adult phytoseiid mites were mounted on slides in Hoyer's medium, dried for one week on a slide-warmer at approximately 45°C, and identified to species.

Mite days, calculated according to Beers et al. (1993), were used to assess the total accumulated phytophagous mite damage over the growing season. For predators, mite days are an index of the total abundance of phytoseiid predatory mites associated with each spray treatment. Differences in densities between treatments were analysed in one-way randomized-block analysis of variance (ANOVA) with the dependent variable being mite days and the independent factor being spray treatment. Differences between treatment means were considered statistically significant if $P < 0.05$, and means were separated using Tukey tests. All density data were log transformed, and the residuals from each ANOVA were examined for normality and homo-scedasticity using SigmaStat 2.0 (Jandel Scientific, San Rafael, CA). Mite counts are expressed as mites $leaf^{-1}$ ± one standard error of the mean. "Peak densities" refer to the highest densities of each mite species observed during the period of this study.

Damage caused by *G. molesta* was assessed on three occasions. The first two samples were taken on 1 June and 13 July. For these two samples, all infested terminals and fruit were removed and examined for the presence of live larvae. All samples from the three trees in each replicate were combined. The third *G. molesta* sample was a fruit sample, taken at the time of harvest on 19 August. Fruit samples consisted of 100 peaches, collected from each three-tree plot in a random fashion. All *G. molesta* counts are the total number of fruit moth-damaged twigs or fruit per replicate plot. Differences between treatments were also analysed using randomized-block ANOVA, as in the mite day analysis.

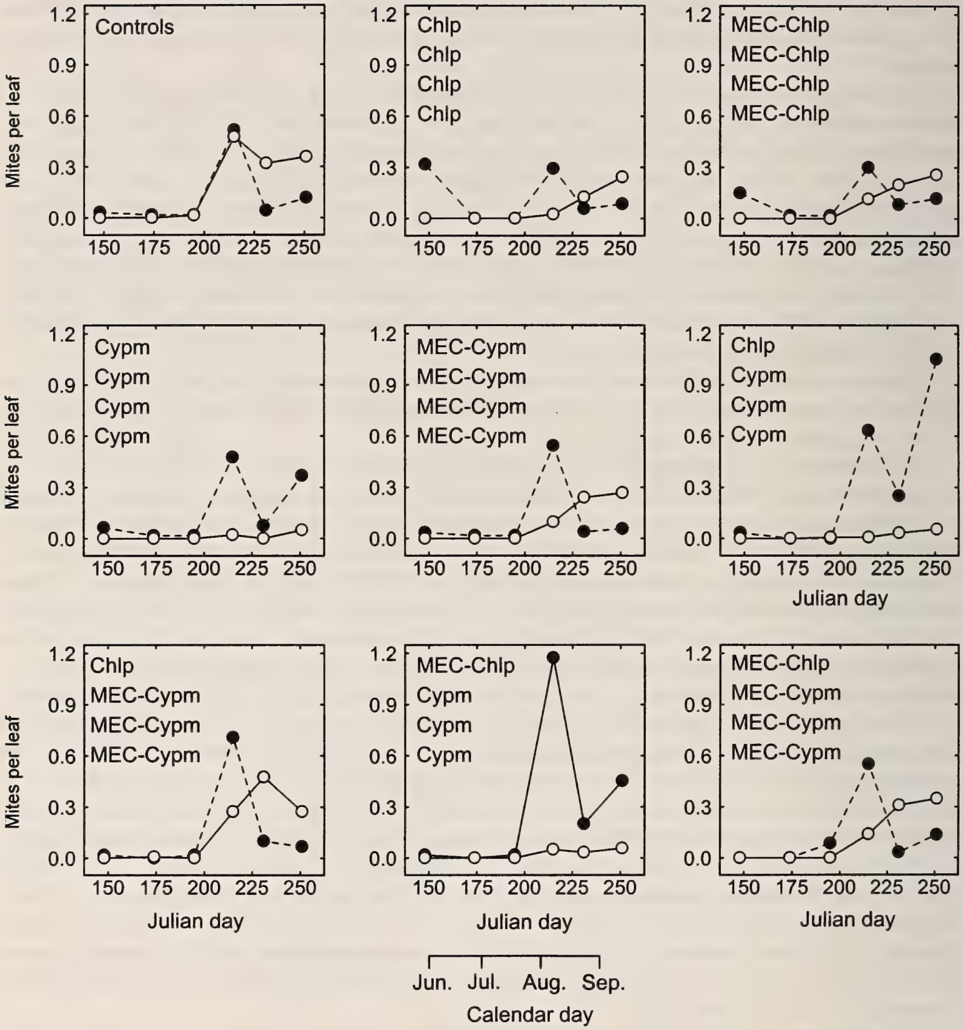

FIGURE 1. Mean densities of mobile stages of the European red mite *P. ulmi* (●) and phytoseiid predatory mites (○) in each spray treatment. $n = 4$. Chlp, Chlorpyrifos; MEC-Chlp, micro-encapsulated Chlorpyrifos; Cypm, cypermethrin; MEC-Cypm, micro-encapsulated cypermethrin.

Results

Predatory mites. Differences in the abundance of predatory mites were observed between spray treatments. In the control treatments, no phytoseiid predators were observed until the third sample on 14 July. The peak density of phytoseiid mobile stages in the control treatments occurred on 3

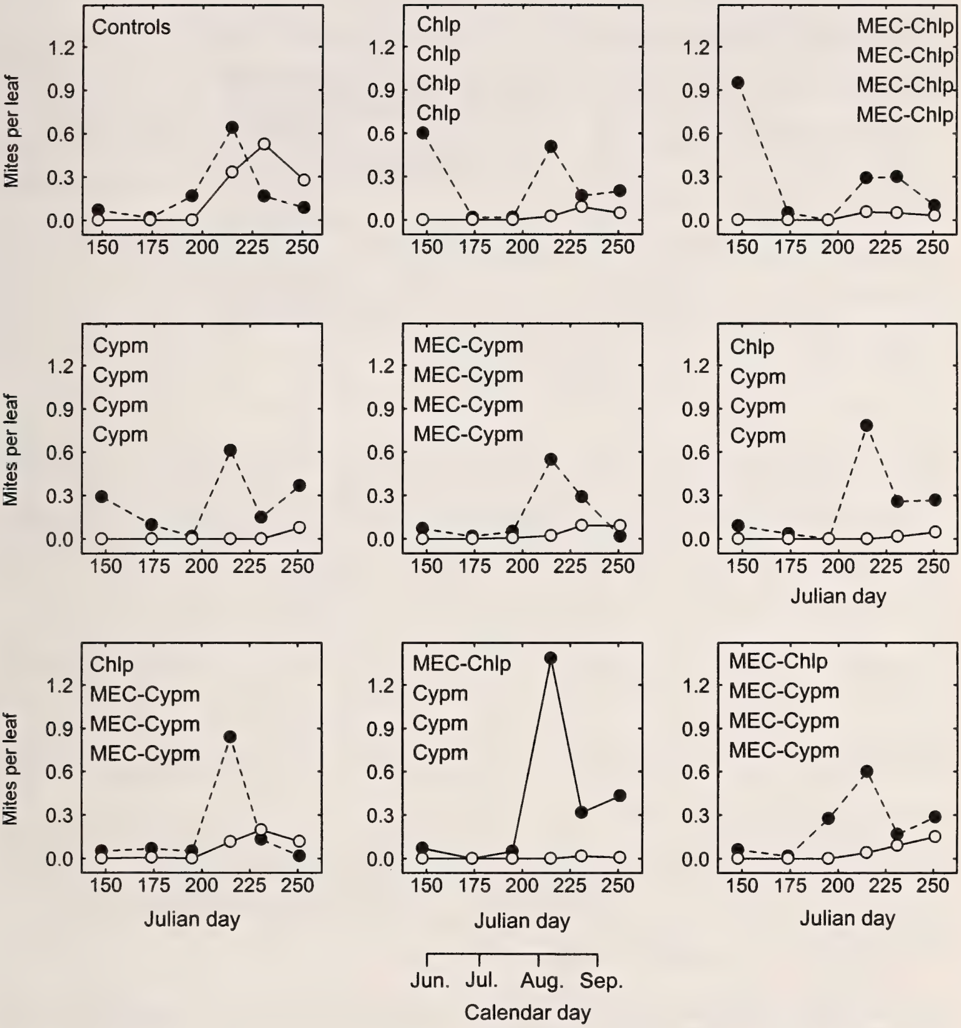

FIGURE 2. Mean densities of eggs of the European red mite *P. ulmi* (●) and phytoseiid predatory mites (○) in each spray treatment. n = 4. Chlp, Chlorpyrifos; MEC-Chlp, micro-encapsulated Chlorpyrifos; Cypm, cypermethrin; MEC-Cypm, micro-encapsulated cypermethrin.

August at 0.48 ± 0.33 per leaf $^{-1}$ (Fig. 1). The peak density of phytoseiid eggs in the control treatment occurred on 19 August at 0.53 ± 0.30 leaf $^{-1}$ (Fig. 2).

For the chlorpyrifos only treatments, micro-encapsulated chlorpyrifos had similar effects on the phytoseiid populations to the chlorpyrifos EC formulation. In these treatments the peak density of mobile stages of phytoseiids occurred in the last sample date, at 0.24 ± 0.07 and 0.26 ± 0.12 leaf $^{-1}$

for the chlorpyrifos and micro-encapsulated chlorpyrifos, respectively (Fig. 1). Similarly, we observed a low density of phytoseiid eggs in both chlorpyrifos treatments (Fig. 2).

Treatments with micro-encapsulated cypermethrin as the sole pesticide had much higher abundances of phytoseiid mites than the cypermethrin EC treatments (Fig. 1). The peak mobile phytoseiid density occurred on the 8 September sample at 0.27 ± 0.11 leaf $^{-1}$ in the micro-encapsulated cypermethrin treatment, compared to 0.05 ± 0.03 leaf $^{-1}$ in the cypermethrin EC treatment (Fig. 1). The peak density of phytoseiid eggs was similar between cypermethrin treatments, at 0.08 ± 0.01 and 0.09 ± 0.04 leaf^{-1} for cypermethrin EC and micro-encapsulated cypermethrin treatments, respectively (Fig 2.).

In the chlorpyrifos and cypermethrin combined treatments, the phytoseiid density was lowest in the treatments which had three cypermethrin EC sprays. In the chlorpyrifos plus three sprays of cypermethrin EC treatment, and the micro-encapsulated chlorpyrifos plus three sprays of cypermethrin EC, phytoseiid mobile densities were always below 0.06 leaf^{-1}. In these treatments, the density of phytoseiid eggs was always below 0.05 leaf^{-1}. In contrast, the treatments with micro-encapsulated cypermethrin had much higher densities of phytoseiids. In the chlorpyrifos plus three sprays of micro-encapsulated cypermethrin treatment, phytoseiid densities peaked at 0.48 ± 0.11 and 0.20 ± 0.01 leaf^{-1} for mobile and egg stages, respectively. In the micro-encapsulated chlorpyrifos plus three sprays of micro-encapsulated cypermethrin treatment, phytoseiid densities peaked at 0.35 ± 0.05 and 0.15 ± 0.02 leaf^{-1} for mobile and egg stages, respectively (Figs. 1, 2).

These chronological results of phytoseiid abundance were reflected in the mite-days analysis. The randomized block ANOVA indicated that the highest number of cumulative phytoseiid mite days occurred in the control and in the chlorpyrifos plus three sprays of micro-encapsulated cypermethrin treatment, which had 18.19 ± 5.61 and 16.36 ± 3.66 mite-days respectively (Table I, Fig. 3). These two treatments had significantly more phytoseiid mite-days than any treatment with cypermethrin EC, which had accumulated 0.92 and 2.06 mite-days (Fig. 3). The spray treatment with four applications of chlorpyrifos had 5.12 ± 2.56 mite days, which was intermediate between treatments with cypermethrin EC, and the control and the chlorpyrifos EC plus three sprays of micro-encapsulated cypermethrin treatment. All other treatments were not significantly different from the chlorpyrifos EC or the control and the chlorpyrifos EC plus three sprays of micro-encapsulated cypermethrin treatment (Fig. 3).

The phytoseiid species observed were *A. fallacis*, *Typhlodromus caudiglans* (Schuster) and *A. andersoni* (Chant). In all but one treatment *A. fallacis* comprised of 66 to 89% of the total number of phytoseiid species which were mounted and identified. In the chlorpyrifos treatment, *T. caudiglans* was slightly more abundant, comprising of 46% of the total (Table II). Only two *A. andersoni* were observed during the study.

Phytophagous spider mites. The only phytophagous spider mite regularly observed throughout the study was *P. ulmi*. In only eight of the 216 samples was *Tetranychus urticae* observed, which was never in abundances of more than 0.13 leaf^{-1}.

The densities of *P. ulmi* were also low throughout the study. The highest density of *P. ulmi* mobile stages observed was 1.18 ± 0.49 leaf^{-1}, in the micro-encapsulated chlorpyrifos plus cypermethrin EC trial. Similar densities were observed in the chlorpyrifos EC and cypermethrin EC trial, which had a peak density of 1.05 ± 0.42 leaf^{-1} (Fig. 1). The two highest densities of *P. ulmi* eggs were also observed in these treatments, at 1.38 ± 0.46 and 0.78 ± 0.38 leaf $^{-1}$ for the micro-encapsulated chlorpyrifos and cypermethrin EC and chlorpyrifos EC and cypermethrin EC treatments, respectively. The lowest peak density of *P. ulmi* mobiles was observed at 0.32 ± 0.25 and 0.15 ± 0.15 leaf^{-1}, in the chlorpyrifos and micro-encapsulated chlorpyrifos treatments, respectively. The lowest density of *P. ulmi* eggs was observed in the micro-encapsulated cypermethrin treatment, at 0.55 ± 0.06 leaf $^{-1}$ on the 19 August sample.

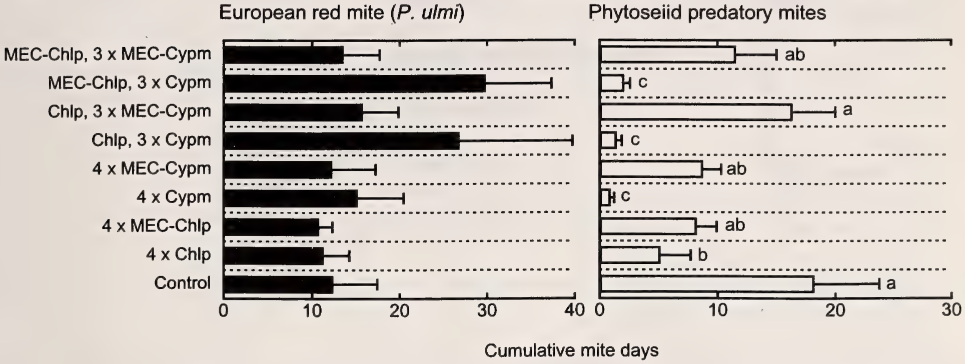

FIGURE 3. Mite days accumulated in each spray treatment. Letters on the phytoseiid predatory mite graph show the results of mean separation by Tukey tests from the randomized block ANOVA. Error bars are one standard error; $n = 4$. Chlp, Chlorpyrifos; MEC-Chlp, micro-encapsulated Chlorpyrifos; Cypm, cypermethrin; MEC-Cypm, micro-encapsulated cypermethrin.

TABLE I. Results from randomized-block ANOVA on the mite-days of phytoseiid predators and *P. ulmi*. The independent variable was the spray treatment.

Source of Variation	DF	MS	F	*P*
Phytoseiid predators				
Treatment	8	0.530	15.964	<0.001*
Block	3	0.135	4.063	0.018
Residual	24	0.033		
Total	35	0.156		
P. ulmi				
Treatment	8	0.077	1.004	0.459
Block	3	0.140	1.823	0.170
Residual	24	0.076		
Total	35	0.082		

* In the ANOVA on phytoseiid mite-days, means were separated using Tukey tests. The results of these Tukey tests are shown on Figure 3.

TABLE II. The predatory phytoseiid species found in each spray treatment. *n*; the total number of phytoseiids mounted and identified in each treatment. The values for *A. fallacis*, *T. caudiglans* and *A. andersoni* are percentages of *n*.*

Treatment	*n*	*A. fallacis*	*T. caudiglans*	*A. andersoni*
Control	54	89	11	0
4 x chlorpyrifos	24	54	46	0
4 x MEC-chlorpyrifos	31	71	29	3
4 x cypermethrin	6	83	17	0
4 x MEC-cypermethrin	32	66	34	3
chlorpyrifos, 3 x cypermethrin	9	78	22	0
chlorpyrifos, 3 x MEC-cypermethrin	60	82	18	0
MEC-chlorpyrifos, 3 x cypermethrin	9	78	22	0
MEC-chlorpyrifos, 3 x MEC-cypermethrin	43	86	14	0

* The mean percentage of species composition for all treatments was *A. fallacis*, 76%; *T. caudiglans*, 24%; *A. andersoni*, 1%. Total $n = 268$

No significant difference ($P = 0.459$) for *P. ulmi* mite-days was observed between any spray treatment (Table I, Fig. 3).

Oriental fruit moth. In the first generation, very few *G. molesta* were observed. The highest number of twigs found to be damaged by *G. molesta* was in the chlorpyrifos EC treatment, which had a total of 2.75 ± 2.75 twigs damaged plot^{-1}. For the control treatment, 0.75 ± 0.50 plot^{-1} was observed. No damage was observed in some of the other treatments (Fig. 4). Results from the randomized-block ANOVA indicated no significant differences in twig damage between any treatment in the first *G. molesta* generation (Table III).

More damage was observed from the second *G. molesta* generation. The highest number of damaged twigs was observed in the chlorpyrifos plus three sprays of micro-encapsulated cypermethrin treatment, with 21.25 ± 6.16 damaged twigs plot^{-1}. This treatment, the micro-encapsulated cypermethrin treatment and the micro-encapsulated chlorpyrifos treatment, had significantly higher numbers of damaged twigs than any treatment which included cypermethrin EC (Table III, Fig. 4). All other treatments had intermediate numbers of damaged twigs. No treatment had significantly higher or lower numbers of damaged twigs than observed in the control (Fig. 4).

In the third *G. molesta* generation, fruit were sampled rather than twigs. While low amounts of damage were observed in all treatments, the highest amount of damage was observed in the micro-encapsulated chlorpyrifos plus three sprays of micro-encapsulated cypermethrin treatment (3.75 ± 1.65 fruit damaged). This value is based on an assessment of 100 fruit from each plot and indicates the low percentage of fruit damaged by *G. molesta* for all treatments (i.e. the highest damage observed per treatment was 3.75%). Similar to the second *G. molesta* generation, the lowest amounts of *G. molesta* fruit damage were in the treatments with cypermethrin EC (Fig. 4). The micro-encapsulated chlorpyrifos plus three cypermethrin EC sprays, and the four cypermethrin EC spray treatment, had significantly less damage than micro-encapsulated chlorpyrifos plus three micro-encapsulated cypermethrin spray treatment (Table III, Fig. 4). As with the second *G. molesta* generation, all other treatments had intermediate numbers of damaged fruit, and no treatment had significantly higher or lower numbers of fruit damage than observed in the control (Fig. 4).

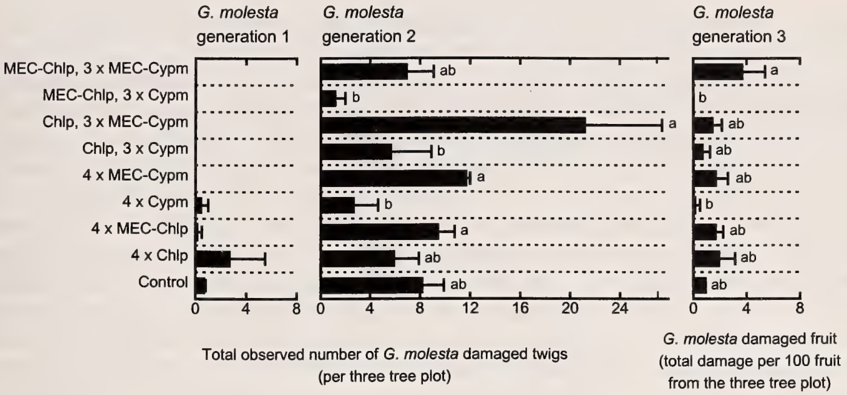

FIGURE 4. The number of *G. molesta* damaged twigs (generations 1 and 2), and the number of damaged fruit per 100 fruit (generation 3) randomly selected from each spray treatment plot. Letters show the results of mean separation by Tukey tests from the randomized block ANOVA. Error bars are one standard error; *n* = 4. Chlp, Chlorpyrifos; MEC-Chlp, micro-encapsulated Chlorpyrifos; Cypm, cypermethrin; MEC-Cypm, micro-encapsulated cypermethrin.

TABLE III. Results from randomized-block ANOVA on the number of *G. molesta* damaged twigs per plot. The independent variable was the spray treatment.

Source of Variation	DF	MS	F	*P*
Generation 1 (twig sample)				
Treatment	8	3.215	0.904	0.529
Block	3	3.954	1.111	0.364
Residual	24	3.558		
Total	35	3.513		
Generation 2 (twig sample)				
Treatment	8	137.437	4.892	0.001*
Block	3	32.407	1.153	0.348
Residual	24	28.095		
Total	35	53.457		
Generation 2 (twig sample)				
Treatment	8	5.000	2.368	0.049*
Block	3	6.028	2.855	0.058
Residual	24	2.111		
Total	35	3.107		

* In each ANOVA with significant treatment effects, means were separated using Tukey tests. The results of these Tukey tests are shown on Figure 4.

Discussion

We demonstrated that the highly toxic effects of cypermethrin to phytoseiid predators were significantly reduced by micro-encapsulation. The peak density of phytoseiids in the micro-encapsulated cypermethrin treatment was 0.27 mobile stages leaf $^{-1}$, which was over five times the density found on trees sprayed with cypermethrin EC. These results are in agreement with others who have found encapsulated pesticides to be less toxic to mite predators (Asquith et al. 1976; Hull 1979). This result also supports an earlier study by Lester et al. (1999), who showed that micro-encapsulated cypermethrin was significantly less toxic to both pyrethroid resistant and susceptible strains of *A. fallacis*. In field spray trials, this study also showed that the use of micro-encapsulated cypermethrin resulted in a significantly reduced outbreak of *P. ulmi* relative to cypermethrin EC. Here, we confirmed the field observations that micro-encapsulated pesticides are less harmful to *A. fallacis* populations, and showed that they are similarly beneficial for the maintenance of the predatory mite *T. caudiglans* populations. It is interesting to note in this study the high abundance of *A. fallacis* relative to *T. caudiglans* on peach trees. In Ontario peach orchards, Putman and Herne (1966) found that *T. caudiglans* was the most abundant and important species in regulating *P. ulmi* populations on peach in Ontario. They described *A. fallacis* as a species primarily associated with the biological control of *T. urticae* (Koch), and *A. fallacis* had limited abundance on peach (Putman 1959; Putman and Herne 1966). Our results show that *A. fallacis* can exist on peach trees in the absence of *T. urticae* and appeared to be the primary species responsible for the biological control of *P. ulmi*.

No significant difference was observed for phytoseiid mite-days between micro-encapsulated chlorpyrifos (mean = 8.20) and chlorpyrifos EC (mean = 5.13) treatments. This result may indicate that there is no, or only a small, decrease in the toxicity of chlorpyrifos due to the micro-encapsulation process. The failure of encapsulation to significantly reduce toxicity to phytoseiid predators contrasts the results with micro-encapsulated cypermethrin. Micro-encapsulation may thus not effectively reduce the toxicity of all pesticides.

From our results, however, we can conclude that the micro-encapsulation of the recommended spray program (one chlorpyrifos and three cypermethrin sprays (Walker et al. in press)) is much more congruent with the maintenance of phytoseiid predators than the current EC formulation of these products.

Although significantly lower numbers of phytoseiid mites were observed in all treatments involving cypermethrin EC, no significant difference was observed between treatments in the density of *P. ulmi* populations. These results contrast with other studies on this experimental farm (Pree 1990; Lester et al. 1998; Lester et al. 1999) and elsewhere (Penman and Chapman 1988; Gerson and Cohen 1989; Croft 1990), where the use of pyrethroids has resulted in significant increases of *P. ulmi* and *T. urticae* populations. We hypothesise that the lack of a spider mite outbreak despite low phytoseiid densities, may have arisen due to the age of the trees (~ 2 years), or the weather patterns of the 1998 summer which were excessively warm and dry with occasional periods of heavy rainfall.

As for phytoseiid mites, the lowest number of *G. molesta* was observed in the treatments involving cypermethrin EC, demonstrating the broad toxicity of cypermethrin EC. For the second generation of *G. molesta*, significantly lower numbers of damaged twigs were observed in the treatments with cypermethrin EC than in treatments with micro-encapsulated cypermethrin. Similarly, in the third *G. molesta* generation, the three treatments with the lowest number of damaged fruit were all treatments involving cypermethrin EC, although these were not always significantly different from other treatments (Fig. 4). The only significant treatment effect in the third generation was that the combination of micro-encapsulated cypermethrin and micro-encapsulated chlorpyriphos had significantly more damage than two of the treatments with cypermethrin EC.

These treatments with cypermethrin EC were the only ones to result in less than 1% of fruit damaged. One percent is the economic threshold as recommended by Pree et al. (1998) and Walker et al. (in press). Treatments which had greater than or equal to 1% damage included the control, chlorpyrifos EC, micro-encapsulated chlorpyrifos, and treatments involving micro-encapsulated cypermethrin. That chlorpyrifos is not as toxic as cypermethrin to *G. molesta* is already known (Pree et al. 1998), but its inclusion is recommended in this spray program to avoid the development of pyrethroid resistance (Walker et al. in press).

It is difficult to make definitive conclusions on the performance of these chemical sprays, because no treatment in any of the three *G. molesta* generations was significantly different from the controls. However, more damage was observed in the second and third *G. molesta* generation in the micro-encapsulated formulation of the recommended spray program relative to the EC formulations. This result may indicate that micro-encapsulation does decrease cypermethrin toxicity to *G. molesta*, but differences between micro-encapsulated and EC treatments were not significant.

Further trials are needed to determine the relative toxicity and field efficacy of micro-encapsulated cypermethrin treatments to pests such as *G. molesta*. If there is a moderate reduction in the toxicity of cypermethrin by the encapsulation process, micro-encapsulated cypermethrin may still be a valuable integrated pest management tool. It may encourage the survival of phytoseiid mites and enhance biological control of *P. ulmi*, but might also be of significance in the biological control of *G. molesta*. There are more than 130 species of parasitoids that have been reported to attack *G. molesta* (Walker et al. in press). The most common of these parasitoids in Ontario peach orchards, *Macrocentrus anacylivorus* (Rohwer), can parasitize up to 74% of *G. molesta* larvae in unsprayed Ontario orchards (Phillips and Proctor 1970). However, parasites such as *M. anacylivorus* are susceptible to pyrethroids (Pree 1979). Perhaps in a micro-encapsulated spray regime, this and other parasitoids would make a greater contribution to the biological control of *G. molesta*.

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STUDIES ON THE ROLE OF THE STIGMAEID PREDATOR *ZETZELLIA MALI* in THE ACARINE SYSTEM OF APPLE FOLIAGE

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Abstract *Proc. ent. Soc. Ont.* 129: 149-155

Over three successive seasons (1993, 1994 and 1995), the role of the predatory mite *Zetzellia mali* Ewing (Acari: Stigmaeidae) was studied in an experimental apple orchard which was used primarily for the evaluation of a new IPM protocol for the combined control of the spotted tentiform leafminer *Phyllonorycter blancardella* Fabricius (Lepidoptera: Gracilariidae) and spider mites. The orchard received a spray regime of pesticides compatible with IPM programs similar to those used in commercial orchards in eastern Ontario, with two exceptions: 1) the omission of acaricides, and 2) the use of reduced rates of the pyrethroid CYMBUSH 12.5 WP (cypermethrin) in selected plots, aimed at the second generation leafminer, instead of the usual full dose aimed at the first generation.

In each of the three years *Z. mali* were more abundant in the pyrethroid sprayed plots than in the control plots. Two reasons are presented to explain this result: firstly the development of resistance to pyrethroids by *Z. mali*, and secondly the reduced competition with phytoseiids which were significantly reduced by the pyrethroid application. *Panonychus ulmi* Koch (Acari: Tetranychidae), *Aculus schlechtendali* Nalepa (Acari, Eriophyidae), and two or three species of tarsonemid mites were the main prey species of *Z. mali*. In 1993 and 1994, all mite populations were so low that it was impossible to draw conclusions about the functional interdependencies of the various species. However, in 1995 *P. ulmi* and *A. schlechtendali* populations reached very high numbers early in the season, followed by major increases in predators and fungivores. This in turn led to the near complete collapse of the pest species later in the season. In the sprayed blocks, *Z. mali* became the dominant predator and contributed to the collapse of *P. ulmi* and *A. schlechtendali* populations. Late in the season, *Z. mali* preyed primarily on tarsonemids and phytoseiid eggs.

Introduction

The most abundant predatory mites in Ontario apple orchards belong to the families Phytoseiidae and Stigmaeidae. *Zetzellia mali* (Ewing) is the most widespread stigmaeid in Ontario apple orchards (Thistlewood 1991). While the role of phytoseiid mites has been broadly studied, the role of stigmaeids in commercial agricultural systems is not well known, and is usually considered to be minor. *Zetzellia mali* feeds predominantly on eggs and quiescent immature stages of tetranychid mites and on eriophyid mites (Santos and Laing 1985). This prey specialization reflects its low motility and low dispersal capacity as compared to phytoseiids. *Zetzellia mali* often has a patchy distribution within orchards.

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As a predator of tetranychids and eriophyids, *Z. mali* can be seen as a complimentary predator of these pests, but as such, it also competes with phytoseiids, and it readily consumes phytoseiid eggs (Woolhouse and Harmsen 1984). It should, however, be noted that *Z. mali* is considered less voracious than most phytoseiids with which it has been compared (e.g. Clements and Harmsen 1990; Lester et al. 1998). Consequently, a definitive opinion as to whether *Z. mali* contributes to, or is detrimental to, the biological control of *Panonychus ulmi* Koch (Acari: Tetranychidae) in apple orchards is difficult to arrive at. In orchards, *Z. mali* can survive long periods of low prey densities (Clements 1991), possibly subsisting on sources of nutrition other than mite prey. It may be able to slow down, or even prevent, population growth of *P. ulmi* at low densities, but it is reported not to be able to maintain mite pests below the economic threshold (Santos 1976). Various authors have discussed the relative merits and demerits of *Z. mali* in the orchard acarine system but, so far, no clear consensus is forthcoming (Santos 1976; Woolhouse and Harmsen 1984; Croft and MacRae 1993; Croft 1994; Thistlewood et al. 1996). Its presence in managed apple orchards also indicates at least some tolerance to common insecticides, but the frequent major population fluctuations from year to year are not understood (Woolhouse and Harmsen 1984).

This communication describes the predatory and competitive roles of *Z. mali* in the foliage-inhabiting acarine system of an experimental apple orchard, part of which was treated with a synthetic pyrethroid. The objective of this study is to provide insight into the ecological role of *Z. mali* in order to develop a better understanding of its potential as a component of stable, multi-species IPM on apple.

Methods

During the growing seasons from 1993 to 1995, mite populations were examined in an experimental apple orchard at the now defunct Smithfield Experimental Farm of Agriculture and Agri-Food Canada near Trenton, Ontario. This study was part of a larger experiment to evaluate a series of IPM control measures for the spotted tentiform leafminer (*Phyllonorycter blancardella*, Lepidoptera: Gracilariidae) and spider mites (Villanueva 1997). In each of these years, the orchard was subdivided into blocks which received various spray rates of the pyrethroid cypermethrin (CYMBUSH 12.5 WP). The orchard was also treated with a standard pesticide regime for commercial apple orchards in Ontario, except for the usual acaricides and pre-bloom oils that are harmful to predatory mites. For details of this spray programme, see Villanueva and Harmsen (1996).

In this communication we only consider in detail the data recorded for the control and low-dose pyrethroid (LDS) treated blocks in 1995. The treatments had five replicates each with three trees per block. The control blocks were sprayed with water. The LDS received 40% (320 g/ha) of the manufacturer recommended dose of CYMBUSH 12.5 WP. The pyrethroid spray took place on 18 July 1995, and was applied with the aim of suppressing the second generation of the leafminer (for details, see Villanueva and Harmsen 1996). Leaf sampling was undertaken bi-weekly; twenty leaves per tree were collected in a random fashion from the middle tree of each block. Samples were brought to the laboratory in a cooler with ice packs, and stored in a refrigerator prior to counting. Counts of all mites on each leaf were made using dissecting microscopes in the laboratory. Phytoseiids were mounted on slides for identification.

The progress of all mite populations throughout the 1995 season was subjected to repeated measures one-factor analysis of variance. The data were transformed as ln(x+1), where x is the number of individuals per leaf (Darmon and Harvey 1987). Mean number of mites of each species low per leaf in the same treatment was compared among the different collection dates. Differences between treatments were tested *post-hoc* using the Scheffe's F-test.

Results

Numbers of *Z. mali* increased by mid-August during each of the three years of the study, reaching their peak by the end of August or mid-September. More active forms of *Z. mali* were found in the LDS blocks than in the control blocks in most of the samples in 1993 and 1994. Total numbers, however, remained low throughout the season during these two years. In 1995, *Z. mali* mean population densities increased significantly (P<0.05) in both the sprayed and the control blocks after the spray. The *Z. mali* increase in the control blocks was significantly less (P<0.05) pronounced than in the LDS blocks (Fig. 1). The pyrethroid had the opposite effect on the abundance of the two phytoseiid species (*Typhlodromus caudiglans* and *Amblyseius fallacis*), which was significantly reduced (P<0.05) after the spray in the LDS blocks. In the control blocks, on the other hand, phytoseiid numbers increased significantly (P<0.05) immediately after the spray, but did decline later in the season (Fig. 1).

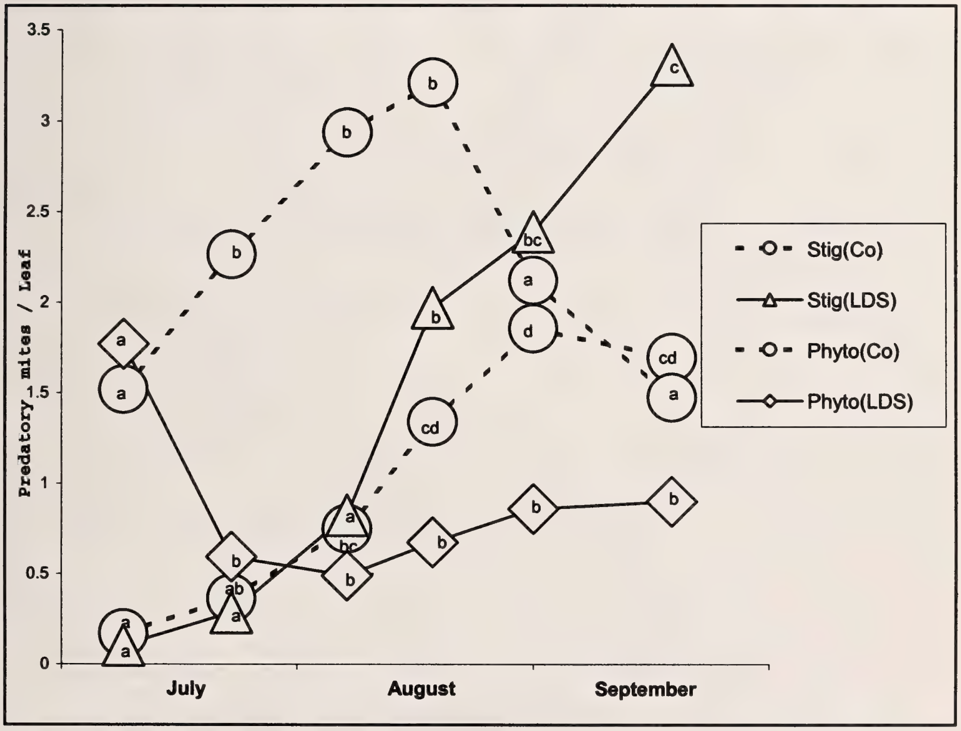

FIGURE 1. Populations of the predatory phytoseiid (Phyto) and *Zetzellia mali* (Stig) mites in 1995. Co: Plots free of CYMBUSH, LDS: plots that received 40% of the manufacturer recommended dose of CYMBUSH against the second generation of *Phyllonorycter blancardella* on July 18. Significant differences are indicated by different letters within the treatment throughout the season using Scheffe's F-test (p<0.05)

The low abundance of *Z. mali* in 1993 and 1994 made it impossible to correlate its population dynamics in a meaningful way with potential prey and competitor species. However, in 1995, *Z. mali* became an abundant predator, especially in the sprayed blocks, despite the early collapse of both *P. ulmi* and *A. schlechtendali*, and the near complete absence of *Tetranychus urticae* (Fig. 2A). In late August and September, *Z. mali* was very abundant, with tarsonemid mites and phytoseiid eggs as the only available prey to sustain the continued presence of these predators. In the control blocks, with a much higher phytoseiid population, *P. ulmi* declined more quickly, and the late season populations of both tarsonemids and *Z. mali* were lower (Fig. 2B).

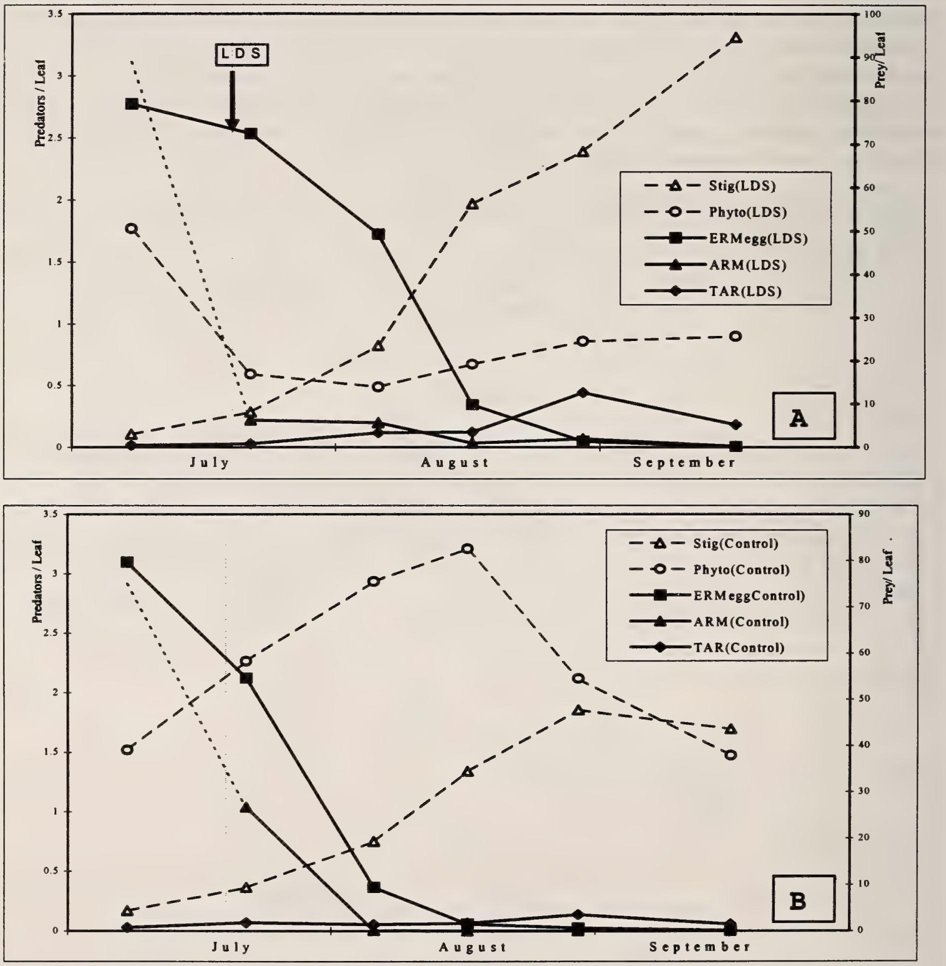

FIGURE 2. Population of the mite complex in 1995. A) in the low dose plots, B) in the control plots. Predatory mites (– – – –): phytoseiids (Phyto), and *Zetzellia mali* (Stig). Prey (———): *Panonychus ulmi* eggs (ERM egg), *Aculus schlechtendali* (ARM) and tarsonemid (TAR) mites.

Discussion

Zetzellia mali was relatively rare in the orchard in the 1993 and 1994 summer seasons, whereas in 1995 it was already present in fair numbers prior to the pyrethroid spray. In all three years, the population increased after the spray, the rate of increase being equal in both the sprayed and control blocks, indicating that the pyrethroid had no measurable effect on this species (Fig. 1). These results are contradictory to those obtained by Li (1991) in the same orchard, and to reports of low pyrethroid resistance of *Z. mali* elsewhere (Hull and Starner 1983; Thistlewood 1991; Li and Harmsen 1992). However, stigmaeids have been described as having developed resistance to other pesticides. Oatman (1973) found tolerance of *Agistenus fleschneri* Summers (Stigmaeidae) to a mix of DDT and captan, while White and Laing (1977) and Croft and Brown (1975) reported that phytoseiids and *Z. mali* have different tolerances to many insecticides. The orchard in which the current research was conducted has been experimentally exposed to low doses of pyrethroids for several years; this may be responsible for the development of a fairly high level of resistance to pyrethroids by the resident *Z. mali* population. We observed no evidence of a repellent effect. The phytoseiids in the same orchard, on the other hand, showed a major mortality/dispersal response to the pyrethroid spray, as a significant ($P<0.05$) decrease in abundance was observed immediately after the pyrethroid application (Fig. 1).

Besides the immediate direct effect of the pyrethroid on the phytoseiids, the other effects of the spray appear to be indirect, mediated via the major effect on the phytoseiids. The *P. ulmi* population decline is significantly more rapid in the control blocks, the tarsonemids do not reach the same levels as in the sprayed blocks, and starting in mid-August, the *Z. mali* population increase is slower in the control blocks. It seems reasonable to assume that the July and August increases in the *Z. mali* populations were sustained primarily by an abundant, but declining, *P. ulmi* population. The more rapid decline of *P. ulmi* in the control blocks is probably the cause of the reduced growth rate of the *Z. mali* population. Competition between *Z. mali* and phytoseiids includes both depletion of shared resources and the consumption of phytoseiid eggs by *Z. mali*, a phenomenon described by other authors (e.g. Clements 1991; Croft 1994; Thistlewood et al. 1996). This example of intra-guild predation has been seen as a major problem in biological control of spider mites, especially when prey densities are low so that phytoseiid eggs can become a major component of *Z. mali* prey (Lester et al. 1998).

By the end of August, both the *A. schlechtendali* and *P. ulmi* populations had been reduced to very low levels in both the sprayed and control blocks. It is significant that over September the phytoseiids and *Z. mali* started to decline in the control blocks due to prey shortages, while in the sprayed blocks the *Z. mali* population kept increasing. The only acarine prey which was available to sustain the predator populations in September were the tarsonemids (see Figs. 2A and 2B). However, *Z. mali* must also have consumed phytoseiid eggs, and it is known that most acarine predators will also consume pollen, fungi, and sometimes plant juices (Wafa et al. 1969). The importance of tarsonemids as an alternative prey in sustaining predator populations in apple orchards deserves further attention. The fungivorous tarsonemid species (*Tarsonemus nodosus* and *T. confusus*) were often found within old leafminer mines together with *Z. mali*, possibly indicating a close ecological relationship (Villanueva and Harmsen 1996).

The high abundance of *Z. mali* in 1995 as compared to the previous two years appears to be in part due to the early very high abundance of *P. ulmi* that year. This observation is important because although *P. ulmi* is not the preferred prey of *Z. mali* when presented with certain prey choices (Clements and Harmsen 1990), population growth of *Z. mali* may occur under these circumstances. The most important effect of high *Z. mali* populations later in the season could be in reducing the *P. ulmi* overwintering population for the following year (Laing and Knop 1983).

Whereas *A. schlechtendali* is considered the favourite prey of *Z. mali* (Hoyt 1969; Santos 1976; Clements 1991), the present results show little relationship between these two species. This result does not necessarily contradict previous published observations, since *Z. mali* utilizes a wide range of prey species in the field.

This study has shown that *Z. mali* can, under certain conditions, develop resistance to pyrethroids. In pyrethroid treated orchards such resistant populations can replace phytoseiids as the most abundant predators of *P. ulmi,* contributing to a reduction in the overwintering *P. ulmi* population. Being an opportunistic feeder, *Z. mali* utilizes several mite taxa as prey, which allows it to remain in the orchard late into autumn, when the main phytophagous prey species are rare, by feeding on the then abundant tarsonemids. The apparent development of tolerance to pyrethroids in *Z. mali*, and its dominant role in the orchard, underscores that the development of resistance to a widely used pesticide in one species can have the potential to alter the composition and trophic dynamics of the entire acarine system. This, in turn, may imply a complete rethinking of the IPM of the system. *Zetzellia mali* may prove to be an important predatory species for future biological control or IPM programs that aim at stabilizing a diverse orchard arthropod community, rather than target specific pests one at a time.

Acknowledgments

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BILATERAL GYNANDROMORPH OF *HYALOPHORA CECROPIA* (SATURNIIDAE) IN NOVA SCOTIA

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The phenomenon of gynandromorphy (lepidopterous) in nature is rare, especially remarkable for an extensively collected group such as the Saturniidae. Hessel (1964) described a bilateral gynandromorph of *Automeris io* Fabricius taken in Connecticut in 1962, and refers to the capture of bilateral gynandromorphs of *Eacles imperialis* Drury in New Jersey and of *Callosamia promethia* Drury in Indiana, both also in 1962. Smith (1998) described a bilateral gynandromorph of *Antheraea polyphemus* (Cram.) ex-cocoon in California in 1994 and suggests that it may have been the result of second generation inbreeding and rearing conditions. There appear to be no records of gynandromorphs of *Hyalophora cecropia* (L) (C. Remington, pers.com.).

Gynandromorphs generally develop a sex abnormality early in their development, thus it is possible for individuals to become bilaterally differentiated, with one side of the body being male, the other side female (Scriber and Evans, 1988). This bilateral condition may be caused by a loss of a Z chromosome in the first cell division of the fertilized egg, or by the development of a binucleate ovum. In sexually dimorphic species, the female side of gynandromorphs develops disproportionately in size, because female cells are larger. Differences in secondary sex characteristics such as the form of the antennae and the abdominal claspers can be quite obvious (Manley, 1971).

Here, I report the capture, at a black light, of what appears to be a bilateral gynandromorph of *H. cecropia,* in early July 1997, in Halifax County, Nova Scotia. The purpose of this note is to present a brief description and a photograph (Figure 1) of the specimen. A series of male and female specimens from various locales within the province, currently in the author's personal collection or in the Reference Collection of the Nova Scotia Museum of Natural History, were also examined. The characters studied are: forewing (size, colour, postmedial lines, discal spot, and red scale character); hindwing (colour, discal spot size and shape); and head (antennae).

Viewed dorsally, the female (left) and male (right) sides are distinctly different. Especially the antennae, which are smaller, but more strongly feathered on the male side, but also the adult wing patterns maintain their separate sexual integrity. The wings appear to be intermediate in size, those on the female side being a bit larger, but the difference is less than between normal male and female wings; the male forewing is also more angled, accentuating the curved forewing tip. The prothoracic collar is a defined grey patch, outlined in black on both forewings, but with more red scaling of the basal area on the male forewing. The wider red postmedial band of both female wings is in sharp contrast to the narrower postmedial red band of the male wings. The outer wing margin of the female forewing contains two black spots along its inner edge; the spots are less prominent on the male side. The white zig-zag and dark eye spot near the forewing tip are more elongated on the female side. The marginal pattern of the male forewing and hindwing is in sharp contrast to the almost non-existent pattern of the same areas on the female side. Pale cream crescents (discal spots) outlined with black and red are present on both the forewing and the hindwing of both sides. However, the discal spot on the forewing of the female side is more elongated, whereas the hindwing discal spot is more broad than the spot on the male hindwing.

There is no clear line of demarcation between the two sides. The body is not obviously bilaterally divided; it is almost 'tapered', appearing more male than female in shape. Without denuding it, it is not possible to say if there are concealed abnormalities of the body integument.

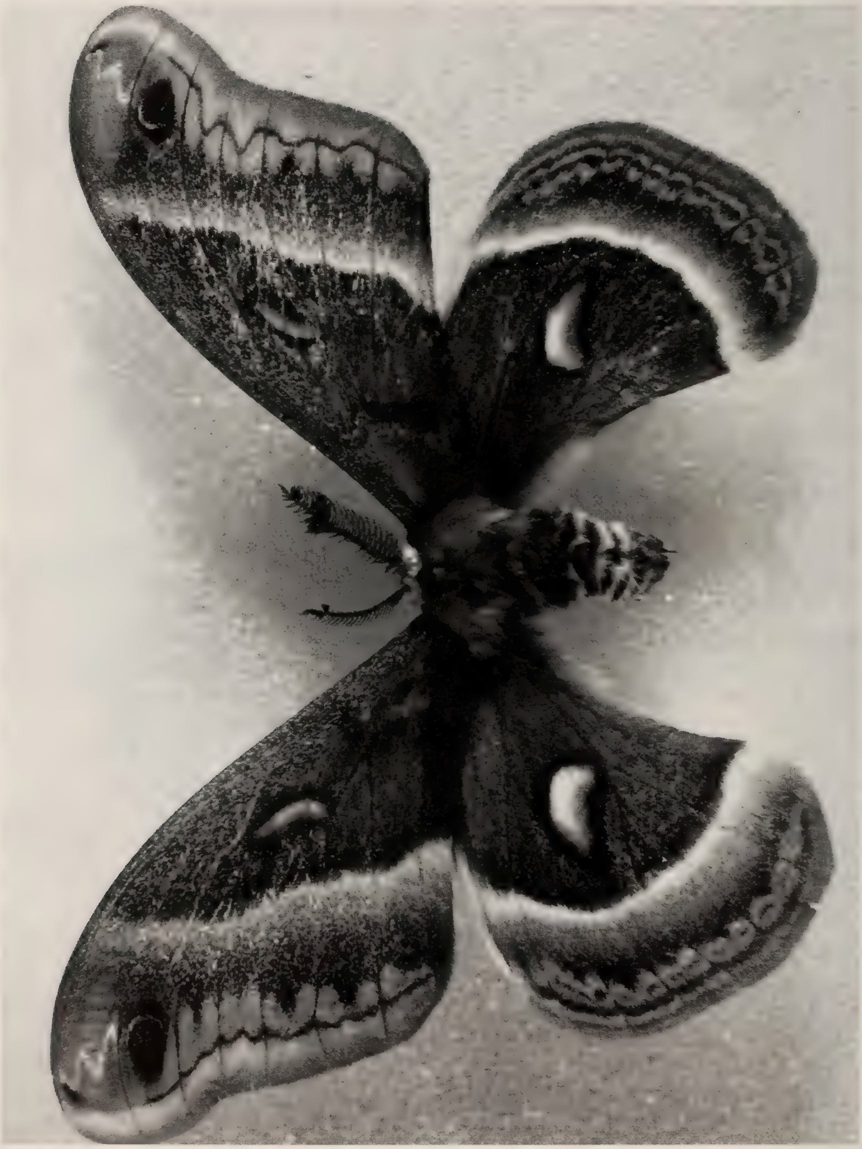

FIGURE 1. Bilateral gynandromorph of *Hyalophora cecropia.*

When compared to normal male and female specimens, all quantitative characters of the two sides of the specimen described above fall within the range of variation found for the respective sexes. I conclude that the specimen is in all probability a bilateral gynandromorph. The specimen will be lodged in the Reference Collection of the Nova Scotia Museum of Natural History.

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HEAVY GALLING BY THE CYNIPID *DIPLOLEPIS SPINOSA* (HYMENOPTERA: CYNIPIDAE) ON *ROSA RUGOSA* IN NORTHERN ONTARIO

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The cynipid wasp *Diplolepis spinosa* (Ashmead) induces large, multichambered galls on the stems of wild rose *Rosa blanda* Ait. throughout central and northern Ontario (Shorthouse 1993). Galls are sparsely distributed within rose patches, usually less than one gall/m^2. However, *D. spinosa* has shifted hosts to the introduced rose *R. rugosa* Thunb. (Shorthouse 1988), a host on which galls can be much more abundant (Shorthouse 1988; Bagatto and Shorthouse 1994). *R. rugosa* is a much sturdier, more vigorous-growing, branched, leafy and floriferous shrub than *R. blanda*.

Galls on both wild and domestic roses are spherical and clothed with stout spines; however, those on *R. rugosa* are on average 25% larger and 50% heavier than those on *R. blanda* (Bagatto and Shorthouse 1994). Galls on *R. rugosa* average 27 chambers/gall whereas those on *R. blanda* average 14 chambers/gall (Bagatto and Shorthouse 1994).

The ecology and anatomy of this gall and its associated component community of parasitoids has been examined (Kelleher 1988; Shorthouse 1993; Bagatto and Shorthouse 1994). In contrast, little is known about how this gall affects the physiology of its host, other than a brief report on how it alters distribution of mineral nutrients (Bagatto et al. 1991). It is likely that host stress increases with the number of galls per stem, but little is known about the number of galls this plant can support without causing host damage. There are no published data on the mean number of galls per plant.

Urban hedges of *R. rugosa* are frequently found with large numbers of galls (see photograph in Bagatto and Shorthouse 1994); however, it is often difficult to count the galls per plant because maturing hedges produce numerous intertwining sucker shoots making it difficult to separate individual plants. Single, isolated roses galled by *D. spinosa* have been found, but in all cases they had fewer than 20 galls.

While collecting galls on wild roses in early May in northern Ontario, I came across two shrubs of *R. rugosa* heavily galled by *D. spinosa* (Fig. 1). Both shrubs were on the front lawn of a rural house about 15 km northeast of Timmins, Ontario. The homeowner agreed to my harvesting the plants and I returned in late July to remove all above ground tissues when the current year galls were mature and heaviest. The purpose of this note is to record the unusually large number of old and current year galls on these two plants along with the dry weights of leaves, flowers and flowerbuds, new and old stems, and galls.

Both roses had been present at the site for nine years and were started from single transplanted canes. Galls appeared on the plants two years after they were planted and, as in urban sites, the first adults of *D. spinosa* would have flown from nearby wild roses. Once established on the new roses, adults from these galls would perpetuate new galls each season. Galls are especially noticeable in the spring (and winter) when the plants are without leaves (Fig. 1). Some of the current year galls were in thick clusters (Fig. 2) and up to 5 cm in diameter. Parasitoids of the inducers were likely present (Bagatto and Shorthouse 1994); however, none of the inhabitants were reared.

Both plants were about 1.3 m in height, had multiple stems (Fig. 1), were about 8 m apart and appeared to have a normal complement of flowers in late July. Although heavily galled, both plants appeared healthy at the time of harvest. All stems were cut at ground level and placed into large garbage bags; no roots were harvested. In the laboratory, current year and previous years'

FIGURES 1–2. 1. One of the *Rosa rugosa* shrubs on a lawn near Timmins, Ontario photographed in the spring showing galls of *Diplolepis spinosa*. 2. Cluster of mature galls of *Diplolepis spinosa* on *Rosa rugosa* in Figure 1.

galls of both plants were removed and counted and then leaves, flowers and buds, current year stems and previous years' stems were separated. All galls and plant tissues were oven-dried at 70°C for two weeks until a constant weight was attained.

Plant 1 had 132 galls; 41 new (current year galls) and 91 old (previous years' galls). Plant 2 had 226 galls, 50 new and 176 old (Table I). New galls on one plant comprised 2.4% of the above plant biomass, but 21.6% of the new stem biomass (new stems comprised 8.6% of the total weight). New galls on plant 2 comprised 3% of the above plant biomass, but 36.2% of the new stem biomass (new stems comprised 5.3% of total weight). Old stems comprised the largest above ground biomass, 63.1% in plant 1 and 55.7% in plant 2. Old galls on plant 1 comprised 5.5% of total plant weight which was 8.0% of the weight of old stems. Old galls on plant 2 comprised 10.3% of total plant weight which was 15.6% of the weight of the old stems. The next heaviest tissue was leaves at 18.5% in plant 1 and 22.7% in plant 2 (Table I). Flowers and developing fruits comprised 2.0% and 3.0% of the total weight respectively.

TABLE I. Weights (g) of galls of *Diplolepis spinosa* and above ground tissues of their two *Rosa rugosa* hosts. Total galls per plant are in brackets.

Tissue	Rose 1 (g)	Rose 1 (%)	Rose 2 (g)	Rose 2 (%)
New galls	88.4 (41)	2.4	133.3 (50)	3.0
Leaves	691.8	18.5	1002.9	22.7
Flowers and buds	73.8	2.0	132.2	3.0
New stems	319.4	8.6	234.7	5.3
Old galls	205.6 (91)	5.5	453.4 (176)	10.3
Old stems	2356.0	63.1	2457.7	55.7
Total (g)	3735.0		4414.2	

Galls of *D. spinosa*, like those induced by other insects (Bagatto et al 1996; Harris and Shorthouse 1996; Abrahamson and Weis 1997; Larson and Whitham 1997), are undoubtedly physiological sinks for carbon assimilates. However, the extent to which sinks caused by this gall affect the host plant is yet to be determined and likely subject to many variables. Even so, from observations of hundreds of galled *R. rugosa* and wild roses, including the above observations, it appears that *D. spinosa* and its galls rarely, if ever, cause the death of their hosts. Of interest, the two plants described here with unusually large numbers of galls, although unsightly, were apparently growing well and flowering normally. Thus, even though a substantial amount of new stem biomass can appear as gall tissues, roses of the rugosa type appear to successfully tolerate the resource drain caused by *D. spinosa* and its galls.

Acknowledgments

Research on galls is supported by the Natural Sciences and Engineering Research Council of Canada and the Laurentian University Research Fund. I thank Mrs. M. Genereux for sacrificing her two roses.

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BOOK REVIEWS

The Butterflies of West Virginia and Their Caterpillars 1997 *by* Thomas J. Allen. University of Pittsburgh Press, Pittsburgh, Pa. XI + 388 pp, 50 Plates. ISBN: 0-8229-5657-8. Paper. $22.95 US

The Butterflies of Canada 1998 *by* Ross A. Layberry, Peter W. Hall, and J. Donald Lafontaine. University of Toronto Press, Toronto, Ont. 280 pp, 32 Plates. ISBN: 0-8020-0898-4. Cloth. $75.00 Can, 0-8020-7881-8. Paper (spiral bound). $29.95 Can.

I have several minimum standards for a *Butterflies of [Fill in the Geographical Blank]*. Most important, the book should cover all species validly recorded in the region. Both these volumes do. *The Butterflies of West Virginia and Their Caterpillars* (BWV) also provides full coverage of a few hypothetical species, like southern strays recorded in bordering areas. *The Butterflies of Canada* (BC) does not do so — understandable given its much larger scope.

Second, there must be range maps, not just verbal descriptions of distribution. Both meet this requirement, with county maps in BWV and dot maps in BC. Both explain the limitation that a mark can only exist on the map if a competent observer documented the record, so that places where a species might likely occur may not be marked. But I prefer this to extrapolated or "smoothed" ranges, for the nature of butterfly knowledge is portrayed better and the value of data is respected — if you think an area should be in range, then jolly well obtain the record. The maps in BC more effectively distinguish the fluke outlier from clusters of multiple records in prime range. But such maps are very laborious to generate, and the sample of data-points is reduced, as precise locality information is necessary.

Third, the text on each butterfly should cover how to identify it in the field (including comparison to the most similar species), habitat and host plant associations, and typical flight periods. Both do so in thorough, scholarly, yet streamlined and accessible language.

Fourth, all species in the book must be shown in colour. Again, both books fully satisfy this stipulation. But for butterflies, a good colour illustration may be worth many more than a thousand words, so I'll belabour this issue. Each volume contains well-focused and properly exposed photographs of specimens in remarkably excellent condition, arranged in plates. In both, the background is white, which works fine except for the White subfamily (Pierinae) in BWV, where I'd prefer a bit more contrast. In BC, the plates are inserted as a group in the midst of the species accounts, which I find disruptive — will the species account I'm seeking fall right before or after the plates, or both? More convenient are the plates grouped together after the species accounts in BWV. Both books arrange the specimens logically in systematic order, with two exceptions. In BWV, the Canadian Tiger Swallowtail (*Papilio canadensis*) appears amongst brush-footed butterflies (Nymphalidae), and the American Snout (*Libytheana carinenta*) follows the Monarch (*Danaus plexippus*). These placements were no doubt necessitated to fit the specimens efficiently into the plates, but it would be helpful if the plates where these butterflies should appear, if in systematic order, had captions to alert readers to the location of these specimens.

Both books show dorsal and ventral wing surfaces of each species. BC always uses half specimens, which consistently follow the convention of showing the left half with the body attached on the right for the dorsal view and the right half with body detached for the ventral. In BWV, dorsal and ventral views are often illustrated with entire specimens, but sometimes with half specimens — seemingly haphazardly as to which half — with the body always attached. Since legs were noticeable on some dorsal half specimens but not always on ventral half specimens, users of BWV must be more alert to the fine print in figure captions to decipher what surface a half specimen shows. Both books conveniently place all captions for a plate on the opposing page and fully cross-reference the page numbers of species accounts with the plate locations of corresponding specimens. But BWV is more user-friendly than BC in that the former's captions also include brief notes on field marks visible in the specimens. However, the arrangement of captions is less user-friendly in BWV than BC. In the latter, each specimen is numbered sequentially, with its caption keyed to that number. But in BWV, captions are listed sequentially by row number, but it's left to the reader to figure out these row numbers in the plates, and the captions are laid out vertically in columns, not horizontally in rows. As a result, readers must work harder to match a caption with its specimen. If I were to use BWV as my primary field-guide (and I would if I lived in West Virginia), I'd cross-reference the specimens and their captions by number as in BC.

Fifth, all views relevant to field identification should be illustrated. If males and females are quite similar, only one sex need be illustrated, and if the dorsal surface is rarely observable except in the hand, then that can be omitted too. But when both dorsal and ventral surfaces are readily observed in the field, and when male and female look different, these should all be illustrated. BWV mostly exceeds this standard since the dorsal and ventral views of both male and female are illustrated for many species, even when not essential for species identification in the field. Not surprisingly, given the larger number of species to illustrate, BC is not as lavish in coverage. Still, for true butterflies (superfamily Papilionoidea), the necessary dorsal and/or ventral, male and/or female views are shown. I was, however, disappointed with BC's illustration of some grass skippers (subfamily Hesperiinae). While the gender dimorphism of dorsal surfaces was adequately illustrated, female ventral surfaces were not provided even when they differ importantly from the male's. Examples include Ottoe Skipper (*Hesperia ottoe*), for which I also find the species account inadequate in describing the ventral female, Dakota Skipper (*Hesperia dacotae*), and Sachem (*Atalopedes campestris*), the only species where I felt BWV's plates are also inadequate.

Distinctive subspecies or forms occurring regularly within the geographic scope of the book should also be shown. Both books illustrate obviously divergent morphs such as the melanistic ("dark") Eastern Tiger Swallowtail (*Papilio glaucus*), leucistic ("albino") sulphurs (subfamily Coliadinae), and 'pocahantas' Hobomok Skipper (*Poanes hobomok*). It's much more challenging for BC to cover all the distinct subspecies within its scope, although this is addressed somewhat by species splits, such as Mustard White (*Pieris napi*) into three new species. Still, I was pleased to find specimens of three subspecies of American Copper (*Lycaena phlaeas*) and two of Coral Hairstreak (*Satyrium titus*). I remain disappointed, as I am with most books, that *alcestis*, the prairie subspecies of Aphrodite Fritillary (*Speyeria aphrodite*), was not illustrated (or adequately explicated in the species account), although specimens of two more similar subspecies (*aphrodite* and *manitoba*) were featured. My crusade about this subspecies shall continue.

Simply meeting my five minimum requirements, as these books creditably approach, is an impressive accomplishment sufficient to recommend them heartily to a wide range of readers. BC (or BC's voice) is a bit more technical — therefore perhaps "meatier" for more advanced students but more intimidating to beginners — than BWV. But both are accessible and valuable to readers of virtually all levels of butterfly knowledge, both within and outside the geographic scope of the books. They serve not only as the new standard references for the butterflies in their regions, but are also extremely valuable outside their geographic scopes because of the detail and quality of the species' coverage.

But both books provide much more than my five minimum requirements, and the content of this additional text overlaps considerably between the books yet also reflects their differences in technical level and geographic scope. In BWV, the six chapters preceding the species accounts are entitled Environment [covering climate, topography, habitat types], Using This Guide [content of the species accounts, key to technical terms], What Are Butterflies? [classification, adult anatomy, life cycle, behaviour], Studying Butterflies [binoculars, nets, photography, rearing, collecting], Butterfly Gardening [appropriate nectar and host plants], and Key to Families and Subfamilies of West Virginia Butterflies. Following the plates and before the glossary are three appendices: List of Scientific and Common Names of Plants [mentioned in text], List of Scientific and Common Names of Butterflies [in West Virginia], and Collection Information for Plates.

In BC, ten unnumbered sections precede the species accounts: How to Use This Book [information provided in the different parts], The History of Butterfly Study in Canada [important past contributors to Canadian lepidopterology], Canadian Geography and Butterfly Distribution [ecological regions and postglacial butterfly biogeography], Butterfly Observation [binoculars, nets, photography], Butterfly Gardening [principles with a few examples], Butterfly Conservation [habitats and butterfly species under threat and why], What Is a Butterfly? [definitions of insects, Lepidoptera, butterflies], Lepidoptera Classification [systematics of subgroups within Order Lepidoptera], Butterfly Life History [thermoregulation, life stages, winter diapause], and Butterfly Systematics [discussion of systematics for debated genera and species]. Following the species accounts and before the glossary are four more sections: Checklist of Canadian Butterflies, Dubious Records, Collecting Guidelines [from the Lepidopterists' Society], and an appendix: Canadian Locations Mentioned in the Text [names and coordinates].

Both books also offer a significant photographic bonus. BWV has excellent colour photographs of the mature live caterpillar of 105 of the 128 species covered in the book. The figure captions identify the plant the caterpillar is on, and for a handful of species, more than one caterpillar is shown to illustrate different colour forms. Not only that, but 63 species of pupae are also illustrated in their typical posture (resting or attached, and at what angle) on a natural-looking substrate. BC provides colour photos of examples for each significant habitat type or ecological zone in Canada, with representative butterfly species shown in life. The site photos are particularly useful, as readers must know what habitat to look for in order to find certain butterflies. Habitat names and even descriptions may not be very enlightening for someone who has never seen that habitat, or part of the world, before.

These are outstanding volumes that I am using extensively, even though I've not been in West Virginia or Canada since these books became available. They are carefully and thoroughly assembled, both in content and presentation. I noticed a few more typographical and printer errors in BWV (most notably, the last line of the butterfly gardening chapter appears as the first line in the next chapter) than in BC, but both have few errors. I highly recommend both books to amateur and professional, beginner and expert.

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The Caddisfly Family Phryganeidae (Trichoptera) 1998 *by* G.B. Wiggins. University of Toronto Press, Toronto. 306 pp. ISBN 0-8020-4241-4. $120.00.

The Family Phryganeidae (Trichoptera) is one of the oldest of the extant case-making caddisfly families, and one which is most commonly found in the higher latitudes of the north-temperate zone. In contrast to most caddisflies, adults can be brightly coloured or patterned, as are the larvae, which are found in a wide variety of habitats including cool streams and rivers, lakes and marshes, bogs, temporary pools, and brackish coastal waters.

Despite being one of the most obvious groups of caddisflies, information on this group has been patchy and widely scattered in the literature, making it difficult to retrieve for all but specialists in the group. The objective of this book was to bring together all the information about phryganeid caddisflies, provide a taxonomic synthesis, and analyse the phylogenetic information to give new insights into the evolutionary history of the family. As would be expected from Glenn Wiggins, he has succeeded wonderfully.

The book is set up with a General Section, including an Introduction, Materials and Methods, General Features, and Evolution, and a Systematic Section including keys and descriptions of the species in the 15 worldwide genera of Phryganeidae. The descriptions given in the morphology sections (adults, larvae and pupae) under General Features are clear and complete, and are augmented by sections on behaviour (including case-making, pupation, flight and oviposition) and ecology. The evolution section is interesting and informative; he clearly sets out his reasoning for assigning species to particular groups and, even as a non-systematist, I got a lot out of this section. In this section, several groups have been synonomized, reducing the number of species recognised in the family by 10%, with study of the larvae along with adults contributing greatly to the current classification.

The book is beautifully written, and richly illustrated. Species keys are given for adults, and generic keys are included for larvae and pupae. The keys are well set up and easy to use, at least for the eastern Canadian species that my students and I used to try out the keys. There were a couple of small frustrations with using the book; for example, the generic key refers continually to Plate 1, which is located at the beginning of the book. Although I had looked at this plate when I first began going through the book, I did not really note the plate number, and when I began using the keys, I had trouble locating it. Reference to Plates was not given in the table of contents (though reference to the distribution maps was), and it was numbered independently of the other figures. Figures, although beautifully drawn, were not always well labelled; a good background in insect morphology is required to identify some of the structures. In particular, my graduate students had some difficulty with the adult genitalia, especially with structures that had been dissected out of the insect, since these were not labelled and were not always easy to put into the context of what you were actually seeing on the insect specimen. We found one apparent typo, on p. 39, where a figure reference to Fig. 189 did not make sense (it should probably refer to Fig. 194, but a careful examination of other figure references showed this to be an isolated incident). Finally, my copy of the book had a major ink smudge on p. 27, making several sentences unreadable.

Despite the inevitable minor problems listed above, this is an excellent book, and will be a valuable addition to the shelf of any aquatic entomologist. Dr. Wiggins has produced an incredible study of this interesting family, which will be of interest to systematists and also to the general worker just wishing to accurately identify phryganeid caddisflies. The figures alone make the book a worthwhile acquisition.

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